ARCGIS HABITAT MODEL FOR THE INDIANA BAT (*MYOTIS SODALIS*) IN TERMS OF POSSIBLE DEVELOPMENT IN MADISON AND DELAWARE COUNTIES, INDIANA.

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Chapter 1: Introduction

1.1 Problem Statement

The Indiana bat (*Myotis sodalis*) has been listed as federally endangered since March 11, 1967 and was provided with protection under the Endangered Species Act of 1973 (Public Law 93-205, Fletcher et al., 2002). Causes for the drastic decline in the Indiana bat population are disturbance of caves used for hibernation, white-nose syndrome and loss of summer habitat (Thogmartin et al., 2012). The Indiana bat is a migratory species that utilizes caves for hibernation during the winter months. They form maternity colonies, usually with less than 100 bats, comprised of female and juvenile bats under exfoliating bark of trees during the summer months (Whitaker and Hamilton, 1998; Humphrey et al., 1977; Menzel et al., 2001). Male Indiana bats roost in separate locations during this time (Hall, 1962). Caves used for hibernation have been protected in an effort to slow the decline of the Indiana bat population (Brack, 1998). Populations of Indiana bats are still declining (U.S. Fish and Wildlife Service, 2009; Callahan et al., 1997; Kurta and Whitaker, 1998). Protecting the Indiana bats summer habitat is now the focus for research and management. Habitat loss has the potential to destroy roosting colonies of the Indiana bat and adversely impact this federally endangered species.

Several large-scale landscape development projects are being discussed and openly debated among for-profit corporations, planners, residents and local government officials in Madison County, Indiana. The creation of Mounds Lake Reservoir was the largest and perhaps most significant project with the hopes of bringing economic development to the region. The reservoir, and other possible development projects, has the potential to destroy high quality Indiana bat habitat within the county. There is much uncertainty regarding Madison County's Indiana bat populations, as they have not been sampled there in at least the last 25 years (Andrew

King Personal Communication, 2015). None of the potential projects for Madison and Delaware Counties have progressed enough to justify sampling for endangered species. Determining if there is potential negative impacts on an endangered species can aid in the decision making processes for these projects. A time and cost effective manner of determining the impact to the Indiana bat is to create a habitat model to determine the amount of critical habitat that could potentially be lost if these projects continue. Using historic data from counties that have been sampled within similar landscapes, a habitat model can be created, verified and then applied to Madison and Delaware Counties. Creation of a habitat model also has the ability to give insight into specific habitat requirements for this endangered species to aid in conservation and management.

1.2 Background

The most recent bat survey conducted in Madison County was in 1990 by United States Fish and Wildlife Service (USFWS) biologist, Andrew King (Andrew King, Personal Communication). During this survey, no Indiana bats were found within Madison County. The Indiana bat roosts in specific riparian forested habitat, usually under the bark of mature dead trees (Carter, 2005). Determining if there are currently Indiana bats within Madison and Delaware Counties, and specifically within the proposed sites for the upcoming development, will be beneficial in further protection of the species, as well as useful information for stakeholders engaged in the decision making processes for future development. However, bats are elusive and difficult to detect and therefore difficult to sample. Further conducting a survey of an endangered species is challenging and requires specialized permits from the United States Fish and Wildlife Service (USFWS), which takes a long period of time to obtain. In order to determine the distribution of the bat species without conducting a complete survey, a habitat model can be created to delineate possible habitat. Habitat models are capable of asserting a scientific statement in regards to the suitability of a habitat for a specific species as well as delineate their distribution within an ecosystem (Guisan and Thullier, 2005).

Habitat-suitability models for the Indiana bat are available for various locations with various levels of habitat detail. Some models address large scale landscape habitat variation and rely on low-detailed GIS data (Romme et al., 1995; Farmer et al., 2002). Other habitat models address regional scales and incorporate low detailed data with small amounts of moderately detailed data to analyze possible Indiana bat habitat (Duchamp and Swihart, 2008; Watrous et al., 2006). Only two models address local scale, such as individual forested areas and use specific detailed data to determine suitable habitat for the Indiana bat (Rittenhouse, 2007; Pauli, 2014) but do not utilize historic presence locations. The current study aims to utilize summer habitat requirements from previous studies and historic presence locations from counties with presence data (Randolph County) to create a habitat suitability model for Madison and Delaware Counties.

1.3 Purpose Statement

The purpose of this study is to (1) create a GIS habitat suitability model for the Indiana bat in Randolph County, Indiana using historic presence locations and environmental variables; (2) determine validity of the model by creating a matrix of environmental variables from GIS map that will be analyzing using multiple Poisson regression; (3) verify the model by applying to Rush and Henry Counties with unique presence locations within the counties; (4) apply the predictive model to Madison and Delaware Counties and determine the potential amount of Indiana bat habitat within the specified counties, as well as in the proposed location of the Mounds Lake Reservoir (Figure 1).

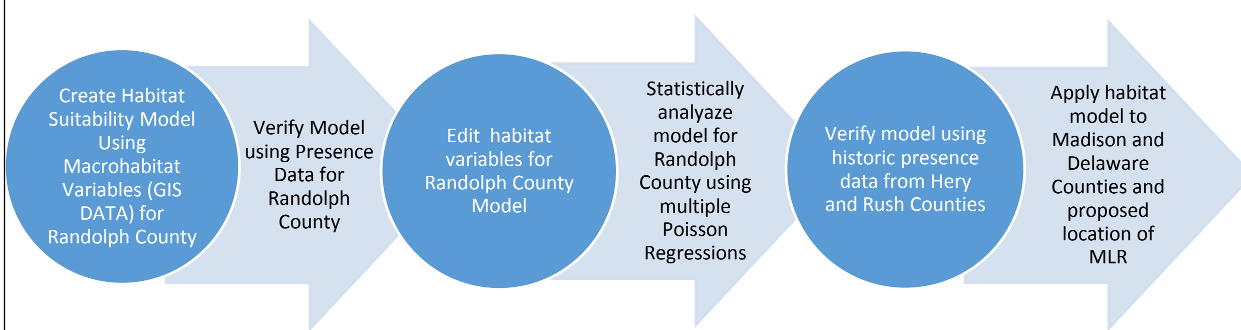

Figure 1: Diagram of process to create habitat suitability model for Madison and Delaware Counties in terms of suitable Indiana bat habitat

Chapter 2: Literature Review

Creating a habitat model for the Indiana bat requires understanding multiple aspects of their ecology. Indiana bats are habitat specialists in terms of their diurnal roosting habitat (Humphrey et al, 1977; Gardner et al., 1991, Kurta et al., 1993; Callahan et al., 1997; Menzel, 2001) and more generalists in terms of their nocturnal foraging habitat (Humphrey et al., 1977; Murray and Kurta, 2004; Menzel et al., 2005; Sparks et al., 2005, Carter 2006, Bergeson et al. 2013). These requirements have been studied and are essential for habitat model creation. There have been multiple habitat models that have been created for the Indiana bat with varying scales, levels of specified data and various approaches. Determining how these habitat models have been generated and applied to managing the species will aid in the overall creation of the habitat model for the Indiana bat in terms of possible development within central Indiana.

2.1 Indiana Bat Habitat Literature

The Indiana bat is a federally-endangered migratory species that hibernates in caves and mines primarily in Missouri, Kentucky, Illinois and Indiana (U.S. Fish and Wildlife Service, 1999). The major causes of the population decline for the Indiana bat have been disturbance of caves used for hibernacula, increase in White Nose Syndrome (WNS) as well as loss of summer roosting habitat. During the 1960's Indiana bat populations began to decline drastically due to human related disturbances of their hibernation caves (Thomson, 1982). After the species was granted protection under the Endangered Species Act of 1973, land managers began installing gates at the entrances of mines and caves to decrease the human disturbance to hibernating bat populations (Brack, 1988). These practices did not result in the increase of Indiana bat populations (Callahan et al., 1997).

Another reason for the drastic decline in the species is the onset of White Nose Syndrome (WNS). WNS is an infectious disease that impacts the muzzle, wings and ears of cave-dwelling bats during the winter season. It is associated with the fungus *Pseudogymnoascus destructans* that was first found in New York in 2006 (Belhert et al., 2009) and has spread throughout the eastern United States. WNS affects multiple species of bats during winter hibernation, including species of endangered or threatened bats such as (Indiana bat (*Myotis sodalis*), Gray bat (*Myotis grisescens*) and Northern long-eared bat (*Myotis septentrionalis*)). WNS has killed an estimated 5 to 6 million bats in eastern North America (U.S. Fish and Wildlife Service, 2017). Indiana bat populations are decreasing at a rate of 10.3% per year throughout their range (Thogmartin et al., 2012). The alarming spread of WNS has greatly influenced bat research and conservation efforts in the eastern United States over the last five years (Zukal et al., 2014; Regan et al., 2015). With efforts being made to understand and manage hibernating habitat for the Indiana bat, more focus has been placed on the summer habitat requirements of the endangered species in terms of landscape level preferences for the species. With increased deforestation and forest fragmentation in the eastern United States, understanding summer roosting habitat requirements is vital to managing this federally endangered species.

During the summer months, female and juvenile bats form maternity colonies and roost in aggregates in wooded areas (Gardner et al., 1991). Female and male bats typically roost separately under loose tree bark or in tree cavities during the day and forage for insect prey during the night (Humphrey et al., 1977; Thomson, 1982; Gardner et al., 1991; Murray and Kurta, 2004; Sparks et al., 2005). Female Indiana bats usually roost in colonies with their young (Humphrey et al., 1977; Thomson, 1982; Menzel et al., 2001) and usually roost together for the entirety of the summer (Menzel et al., 2001). Female Indiana bats typically give birth to a single young in the early summer (Mumford and Calvert, 1960; Humphrey et al., 1977; Foster and Kurta, 1999). In terms of their foraging habitat that they utilize for feeding nocturnally, habitat has been found in riparian, flood plain and open canopy clearings such as pastures (Humphrey et al., 1977; Carter, 2006; Womack et al., 2013). Even with conservation efforts to preserve hibernating caves, populations of Indiana bats has still declined through the eastern United States (U.S. Fish and Wildlife Service 2009) therefore, understanding and managing summer habitat for the Indiana bat is critical.

2.1.1 Diurnal Roosting Habitat

Researchers have studied the foraging and roosting requirements needed for Indiana bats during the summer months. Roosting habitat is essential for Indiana bats because these sites are where mothers give birth and raise their young (Thomson, 1982; Humphrey et al., 1977). Also, roosting habitat is important for bats, because it provides shelter from adverse precipitation and solar radiation as well as protection from predators (Kunz, 1982). The Indiana bat utilizes two types of roosts: primary and alternate. A primary roost is usually defined as a roost that is used over 2 days and has occupancy of over 30 bats (Callahan, 1997). Alternate roosts are used less frequently and by fewer bats.

Indiana bats roost (primary and alternate roosts) predominantly under the exfoliating or peeling bark of dead or dying trees (Humphrey et al., 1977; Gardner et al., 1991; Callahan et al., 1997; Brady, 1983; Timpone et al., 2010). The size of the roost tree has also been studied, and Indiana bats show a preference for large trees with a diameter at breast height (dbh) >22 (Kurta et al., 2002; Lacki et al., 2009). Larger trees may be selected by bats for many reasons. The larger the tree, the more outward surface area and the more potential for exfoliating bark. Also, beneath bark of dead trees has the potential to provide adequate space for air circulation and for bats to change their positions while remaining hidden (Garner and Gardner, 1992). The species of tree that the roost is placed in does not seem to be as important as the bark structure and size of the tree (Romme et al., 1995). Some of the species of tree that have been utilized for roost locations for the Indiana Bat are as follows: *Carya spp., Acer spp., Fraxinus spp., Quercus spp., Ulmus spp., Pinus spp. and Planus spp*. (Kurta et al., 1993; Callahan et al., 1997; Menzel et al., 2001; Ford et al., 2002). The Indiana bat also shows a preference for bottomland forests and riparian areas (Callahan et al., 1997; Carter, 2006). This could be because close proximity to a water source could be beneficial in energy conservation during roosting months.

Thermal regulation is another aspect of Indiana bat roost site preferences. Primary summer roost sites have been found to be in trees that have some degree of direct sunlight (Humphrey et al., 1977; Kurta et al., 1993; Callahan et al., 1997; Britzke et al., 2003). The reasoning behind this preference could be the thermal advantages of raising young with increased solar radiation (Callahan et al., 1997; Menzel et al., 2001). Alternate roost sites have been found to have less direct sunlight on the roost tree which could have benefits for the Indiana bat outside of raising young, such as increased use for foraging habitat (Callahan et al., 1997).

2.1.2 Nocturnal Foraging Habitat

The Indiana bat relies on nocturnal habitat to forage for insects. Foraging habitat may be more varied, compared to diurnal roosting habitat, which seems to require specific habitat requirements (Pauli et al., 2014). They leave their roosts at dark and can travel a maximum of 4 km (Sparks et al., 2005) away from their roost site. Indiana bats seem to have a preference for wooded areas for foraging (Murray and Kurta, 2004; Menzel et al., 2005; Sparks et al., 2005;

Womack et al., 2013; Kniowski and Gehrt, 2014). Wooded habitat areas that Indiana bats have been found foraging include; riparian habitat (Humphrey et al., 1977; Kessler et al., 1981; Brack, 1983), upland woodlots (LaVal et al., 1997; Brack, 1983) and bottomland floodplains (Carter, 2006; Bergeson et al., 2013). Though wooded habitats seem to be preferable, Indiana bats have occasionally been found foraging in open areas, such as agricultural fields (Sparks et al., 2005).

Other habitat characteristics have been studied in terms of the Indiana bat nocturnal foraging habitat, such as proximity to hydric habitats. Humphrey et al. (1977) found that Indiana bats were found in riparian habitats, near streams during foraging. Other studies have found Indiana bats foraging in upland forests and areas not in proximity to riparian habitat (LeVal et al., 1977). The need for riparian habitat for Indiana bat foraging is still unknown. Regarding the amount of canopy cover and Indiana bat nocturnal habitat, Brack noted that there were canopy gaps where Indiana bats were caught in their foraging habitat (1983). Indiana bats were found in Missouri in a stand that had been heavily logged and had lost many large overstory trees, creating canopy openings (Callahan, 1997). In addition to canopy gaps, Humphrey et al. (1997) noted that Indiana bats forage between 2 to 30 meters height on average.

2.2 Habitat Analysis Literature

Several summer habitat models have been created for the Indiana bat (Romme et al., 1995; Farmer et al., 1997; Rittenhouse et al., 2007; Weber and Sparks, 2013). Romme et al. (1995) created a habitat suitability model for the Indiana bat. They hypothesized that availability of food and roosting resources, which are dependent on specific habitat characteristics, would create an index of suitability for Indiana bat habitat (Romme et al., 1995). The variables they used to define suitable roosting habitat were: percent overstory canopy cover, mean diameter at breast height (dbh) of trees, density of trees, density of snags, and percent cover in overstory canopy. The variables that they used to define suitable foraging habitat were: percent overstory canopy cover, size of trees, distance to water and forest cover.

Farmer and Cade (1997) conducted a field test to test the habitat suitability model for the Indiana bat that Romme et al. (1995) created. In terms of foraging habitat, Romme et al. created a model that assumed feeding occurs in forests and therefore feeding by bats is impacted by openness of understory and anthropod abundance (1995). The team of professionals did not believe there was substantial research to validate these claims. They proposed using habitat, food-producing cover types to define suitability of foraging habitat (Farmer, 1997). In terms of roosting habitat, Romme et al. measured stand-level forest characteristics. The panel of professionals believed that a direct assessment of individual roost trees was a more accurate approach to understanding Indiana bat habitat. They defined a set of five conditions that would constitute viable Indiana bat roosting habitat; 1) trees greater than 22 dbh, 2) snags greater than 3m in height, 3) no overarching tree canopy or understory canopy within 2m of the tree bole, 4) exfoliating bark over at least 25% of the tree surface, and 5) tree bole free of vines (Farmer, 1997). They also assumed that a landscape with less than 5% forest would be unsuitable Indiana bat habitat. A habitat with 20 to 60% forested habitat would be desirable for roosting habitat (Farmer, 1997). They also described the need to verify and validate the HSI (habitat suitability index) model that was proposed by Romme et al. (1995) by conducting mist netting (Farmer, 1997).

Rittenhouse et al. (2007) created habitat suitability models for 10 wildlife species using GIS data for the Central Hardwood Region of the Midwestern United States. They used data from Menzel et al. (2001) about literature on habitat requirements for the Indiana bat, and Romme et al. (1995) and Farmer et al. (1997) for model comparisons (Rittenhouse, 2007). They created four suitability index (SI) variables that were combined to create a HSI that encompassed suitable Indiana bat summer habitat. The first SI they created identified maternity roost trees as a function of snag suitability and density. They proposed that snags (dead broken trees) with a dbh of greater than 50 cm were optimal for Indiana bat roosting habitat (Rittenhouse, 2007). The second SI they created addressed open habitat and early successional forest that is useful for the Indiana bat for foraging habitat. They delineated the amount of early successional habitat based on stand age. A stand less than 20 years of age received the highest suitability value (Rittenhouse, 2007). The third SI they created identified the distance from the roost tree to water. A roost tree less than 1000m away from water was considered optimal (Rittenhouse, 2007). The fourth SI they created evaluated roost exposure to solar radiation. They used distances in GIS to determine appropriate gaps in forest canopy (Rittenhouse, 2007). They then combined the four SI measurements to create a HSI for the foraging and roosting needs during the summer for the Indiana bat.

Weber and Sparks (2013) compared known summer locations of Indiana bats with environmental data using the program MaxEnt. They found that 81-98% of the recorded Indiana bat locations were found within their modeled habitat (Weber and Sparks, 2013). They used occurrences of Indiana bats in Indiana, Kentucky, Tennessee, Ohio, West Virginia, Pennsylvania, New York and New Jersey to determine the validity of 18 environmental variables found in previous research. Using statistical analysis, they were then able to determine which variables were significant in terms of where Indiana bats were found in specific regions. They found that for Indiana and Ohio, predominantly agricultural based states, riparian forest and forest edges with adjacent fields were the most suitable habitat for the Indiana bat.

Pauli (2014) gathered acoustic readings of Indiana bats within state forests in Indiana. He then created models using habitat variables to create an occupancy model using MaxLike, a maximum likelihood approach to species modeling. The results showed environmental variables that predicted the occurrence of the Indiana bat (Pauli, 2014). The habitat variables that he used were forested areas, adjacency to non-forested areas (developments, agriculture), Indiana bat hibernacula, streams and public roads. From these environmental data in conjunction with the echolocation data collected, he was able to determine the variables that predicted the presence of the Indiana bat. He found that occupancy by Indiana bat was highest when forested habitat was the within 1km. This was surprising since Indiana bats have been thought of as forested dependent for their roosting and foraging habitat (Menzel et al., 2005). Pauli described the anomaly as the species selecting habitat from a homogeneous habitat therefore they selected heterogeneous habitats (forest gaps and agriculture) as opposed to areas with higher amounts of proportional forest cover (Pauli, 2014). In terms of forest habitat for nocturnal habitat, Pauli found that the occupancy of the species was greatest when the location had been recently harvested or had not been harvested in a long period of time. Pauli also found that proximity to water and anthropogenic habitat (originating from human activity) impacted the occupancy of the Indiana bat (Pauli, 2014).

Cruz and Ward (2016) also used MaxEnt to determine how the environmental variables of land cover, forest fragmentation, solar radiation, slope, proximity to water and elevation influenced foraging habitat suitability (all environmental variables delineated using ArcGIS) within West Virginia. Their habitat model created using MaxEnt delineated large tracts of forest cover with low to modest slopes, road corridors and areas with high solar radiation to have the most importance on Indiana bat foraging habitat within their region (Cruz and Ward, 2016).

They found that slope had the highest percent contribution to the overall model (30.3%), with low slopes of 1-20° being the most suitable. Land cover contributed to the overall model with 23.3% contribution, and proximity to permanent water contributed to the model 9.2% (Cruz and Ward, 2016). Their study followed previous studies (Carter et al., 2002; Ford et al., 2005) in that Indiana bats require canopy closure for their roosting and foraging habitat as well as being within a close proximity to a permanent water source as a contributing factor (9.2%). Hammond et al. (2016) also used MaxEnt to identify landscape level roosting habitat characteristics for the Indiana bat. They conducted 26 candidate models, in which two of the models accounted for 0.93 of the AIC (Akaike Information Criterion) values. They found that elevation and forest type were the best predictors of species occupancy followed by aspect and distance to ridges within the Southern Appalachians in which they were sampling (Hammond et al., 2016).

Ford et al. (2016) examined the issue of creating presence probability models for bat species (Northern Long-Eared Bat) using historic data, based on the inferences that can be concluded from the model. Using historic data for a species with reduced population sizes may be beneficial because of difficulty collecting current data. They created habitat models using MaxLike from historic data for the Northern long-eared bat and compared them to known habitat preferences for the species. They concluded that the major limitation in using historical data for habitat model creation is to not violate the assumption of representative sampling. Therefore they warned against the use of historic data using more than one type of sampling method.

As explained in previous examples, there have been a multitude of techniques used to created habitat models for illusive species, such as the Indiana bat, over time. Recently, habitat analysis software such as MaxEnt and MaxLike has been commonly used as pragmatic ways of determining preferred habitat for wildlife species. MaxEnt (more commonly used) is a computer modeling program that is able to determine if the distribution of presence locations is correlated with specific environmental variables and probable species occurrence or habitat suitability based on those environmental variables (Phillips et al. 2006). Some studies have found that MaxENT operates well in comparison to other modeling methods (Phillips and Dudik, 2008; Phillips et al., 2006). MaxEnt has also been criticized for multiple misapplications (Yackulic et al., 2013) because the suitability index results are on an arbitrary scale (habitat quality on a scale of 0-1) rather than a definable quantity of habitat values (defining specific habitat requirements such as tree stand height or canopy closures). Yackulic et al. (2013) also found that MaxEnt requires strict constraints of study design (difficulty in using historic data), in that 87% of studies using MaxEnt suffered from sample selection bias.

Another method for creating habitat models is Poisson Point Process. Renner and Warton (2013) compared the equivalence of MaxEnt with Poisson Point Process in terms of species distribution modeling for ecology. They found that MaxEnt and Poisson Point Process are mathematically equivalent. No studies were found to use Poisson Point Process in terms of Indiana bat habitat modeling as of yet, but the process can be described as suitable for historic data for the species, compared to other methods. The current study utilized historic data to create a habitat model for the Indiana bat. A matrix of environmental variables compared to the historic presence locations were statistically analyzed using Poisson Regression to determine overall validity of model and the importance of each habitat variable on the overall model.

Chapter 3: Methods and Procedures

3.1 Study Area

The entire study area is within East Central Indiana (Figure 2). The training data used to create the habitat model for the Indiana bat was presence locations that were located within Randolph County. The habitat model was then verified using separate test data from Rush and Henry Counties, each having similar ecosystems, similar amounts of agricultural, forested and developed land. Once the model was verified, it was applied to Madison and Delaware Counties to determine the amount of Indiana bat habitat within these areas and specifically within the proposed location of the Mounds Lake Reservoir, which would fall within these counties.

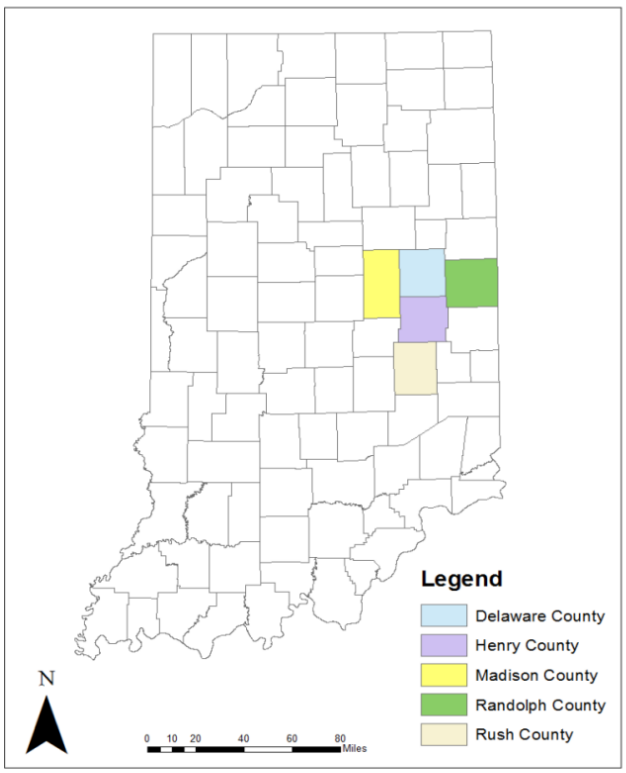

Figure 2: Counties within Indiana used for training (Randolph), test (Henry and Rush) and application (Madison and Delaware) for habitat model creation.

Randolph County is along the eastern edge of central Indiana. Randolph County is approximately 453.30 square miles, 452.38 square miles of land and 0.94 square miles of water (U.S. Census Bureau, 2010). The county is part of the Bluffton Till Plain and the new Castle Till Plains. Randolph County is generally covered in glacial till and has a small percentage of streams and lakes. There are approximately 36.07 square miles of forested land, 45.97 square miles of agricultural land and 32.52 square miles of development within Randolph County (Figure 3).

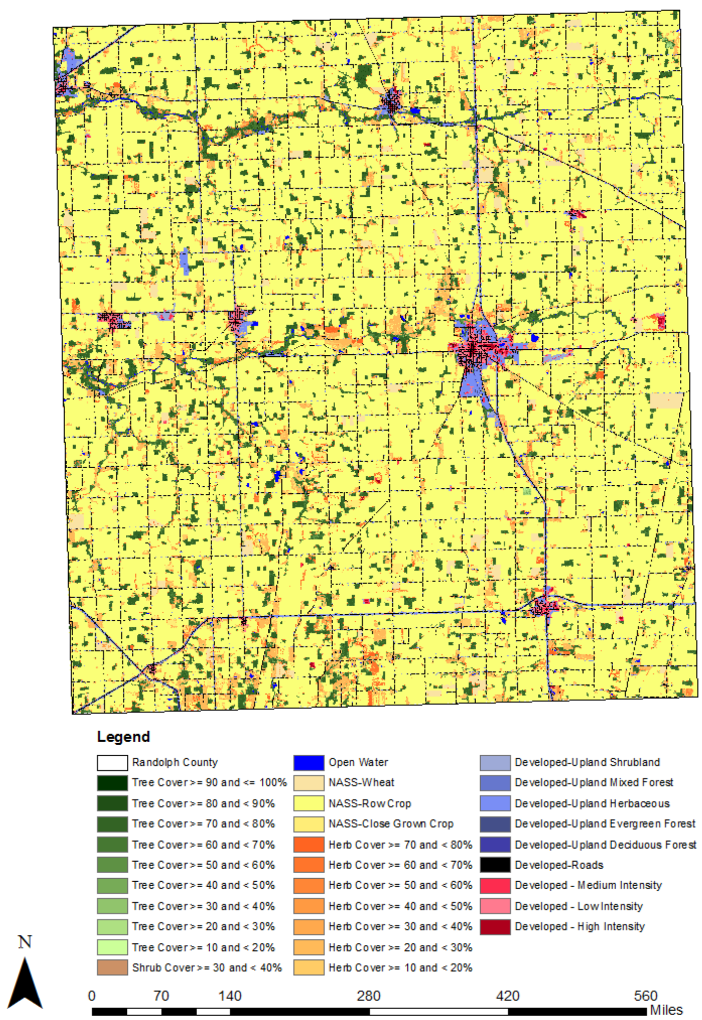

Figure 3: Land use within Randolph County, Indiana

Rush and Henry Counties are also located in east central Indiana, southeast of Indianapolis (Figure 2). Rush County is approximately 408 square miles, 407.66 square miles of land and 0.34 square miles of water (U.S. Census Bureau, 2010). The region is part of the New Castle Till Plains. There are approximately 29.53 square miles of forested land, 36.77 square miles of agricultural land and 25.35 square miles of development within Rush County (Figure 4). Henry County is approximately 395 square miles, 392 square miles of land and 3 square miles of water (U.S. Census Bureau, 2010). The region is also part of the New Castle Till Plains. There are approximately 38.32 square miles of forested land, 31.41 square miles of agriculture and 38.63 square miles of development within Henry County (Figure 4).

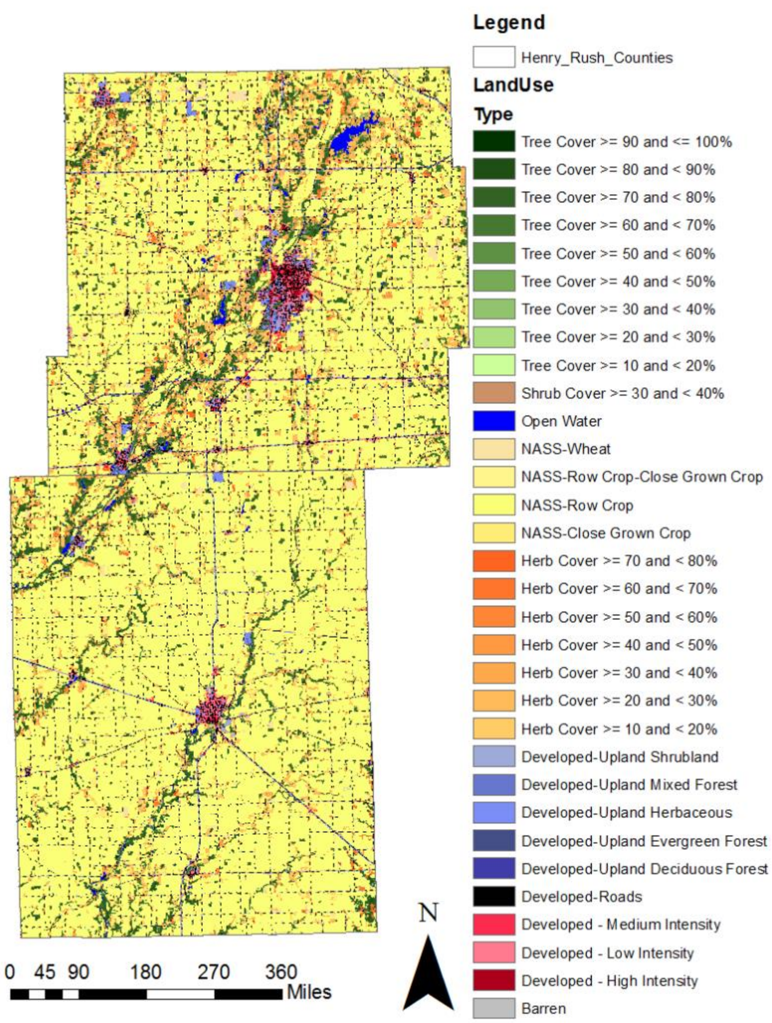

Figure 4: Land use within Henry and Rush Counties, Indiana

Madison and Delaware Counties are located in east central Indiana, northeast of Indianapolis (Figure 2). Madison County is approximately 452 square miles, including 451 square miles of land and 1 square mile of water (U.S. Census Bureau, 2010). This region is part of the Tipton till Plain, having been traversed by both the Illinoian and Early Wisconsin ice sheets. Madison County is generally covered by glacial till predominantly with a few lakes and streams (Welch, 1935). There are approximately 32.66 square miles of forested land, 32.51 square miles of agricultural land and 72.55 square miles of development within Madison County (Figure 5). Mounds State Park lies within Madison County and consists of 252 acres of forested habitat, unique wetland (fen) and archaeological significant sites (Mounds Lake Discussion, 2014). Delaware County is approximately 396 square miles, 392 square miles of land and 4 square miles of water (U.S. Census Bureau, 2010). This region is part of the Bluffton and New Castle Till Plains. There are approximately 36.31 square miles of forested land, 26.25 square miles of agricultural land and 62.09 square miles of development within Delaware County (Figure 5).

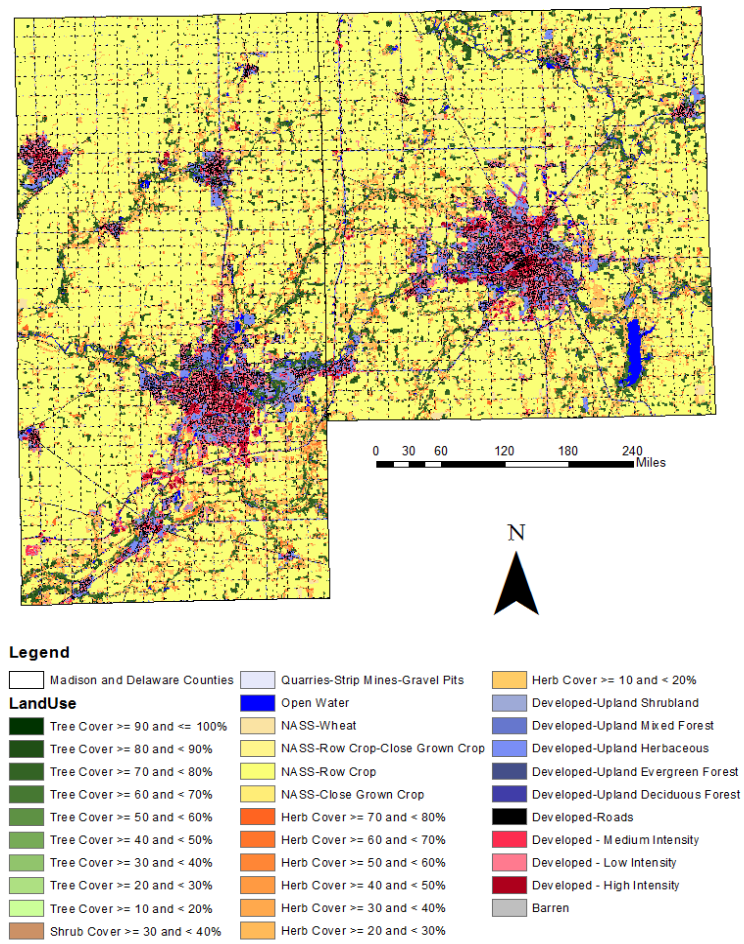

Figure 5: Land use within Madison and Delaware Counties

3.2 ArcGIS Habitat Model

Small tracts of land with specific habitat requirements can be used as roosting habitat but may not be adequate as foraging habitat. Indiana bats require large tracts of land for foraging and require close proximity to water with moderately open canopies for both foraging and roosting (Humphrey et al., 1977; Kurta et al., 1993; Callahan et al., 1997; Britzke et al., 2003; Farmer et al., 1997; Callahan et al., 1997; Carter, 2006). If the tract is large enough to forage but has the specific requirements needed for roosting, the habitat will be deemed suitable for Indiana bat summer habitat. Pauli (2014) discovered the roosting habitat had a greater effect on the overall habitat suitability of an ecosystem than did foraging habitat. This was because of the limited amount of ecosystems that meet the specific requirements of roosting habitat. Requirements for foraging habitat are less specific, therefore it may be easier to find suitable foraging habitat (Pauli, 2014). This describes a situation in which roosting habitat may be the limiting factor for Indiana bats in their summer habitat. Thus, for the purposes of this study, roosting habitat will be defined as a prerequisite for foraging habitat.

ArcGIS (10.3.3) was used to create a habitat model for the Indiana bat in Randolph County, Indiana. Previously published literature was used to determine the habitat features that are beneficial to the presence of the Indiana bat in terms of their summer foraging habitat. The amount of summer habitat was defined as the habitat used to roost during the summer months as well as forage for food diurnally. The requirements for roosting habitat, discussed in the literature review section, are well researched and involve specific habitat requirements. These specific habitat requirements were used to delineate the habitat variables listed below to create a habitat model within the study area (Randolph County) using ArcGIS.

3.2.1 ArcGIS Habitat Model Variables

1. Tracts of forested land: 20-60% forested habitat (Farmer et al., 1997)

The amount of forested area has been found to be significant in providing appropriate roosting habitat for the Indiana bat (Farmer et al., 1997). Forested habitats have a higher probability of having dead or dying trees. In terms of habitat used for foraging, the Indiana bat seems to not prefer completely wooded habitats (Farmer, 1997). The amount of forested land within the study area was determined using data from the LANDFIRE program (LANDFIRE.US_130EVC) that uses a 30-m grid format (Wildland Fire Science 2013a). LANDFIRE is a cooperative initiative between the U.S. Department of Agriculture and the U.S. Department of the Interior and the Forest Service that provides GIS spatial data layers that are updated regularly. The data includes the current land uses for all of central Indiana. The data was refined by using the Geoprocessing Clip tool to specify the data within the study area. The relevant forest cover percentages (20-60%) were exported and the raster data was converted to polygon data using the Geoprocessing tool Raster to Polygon (simplifying polygons within the program).

2. Less than 1000m away from water source optimal (Rittenhouse, 2007)

Rittenhouse (2007) suggested that a distance farther than 1000m away from a water source would deter Indiana bat from roosting. This could be because close proximity to a water source could be beneficial in energy conservation during roosting months. Two data sets from the U.S. Geological Survey were used to create a comprehensive file of water resources (U.S. Geological Survey and the U.S. Environmental Protection Agency 2008, U.S. Geological Survey and the U.S. Environmental Protection Agency 2016) that could be used by the Indiana bat (1.

HYDROGRAPHY_HIGHRES_WATERBODYDISCRETE_NHD USGS, 2. HYDROGRAPHY_HIGHRES_WATERBODYLINEAR_NHD_USGS: Rivers, Inundation Areas, Canals, Submerged Streams and Other Linear Waterbodies in Watershed in Indiana_1:24,000_Polygon Shapefile). The data was combined using Merge and was refined to the study area by using the Clip Geoprocessing tool. A 1000 meter buffer was created around all water bodies and was used as an indicator of species occupancy.

3. Large trees greater than 22 cm dbh (Gardner, 1991)

The Indiana bat has been found to roost in larger trees. Gardner (1991) found that the Indiana bat prefers to roost in trees larger than 22cm dbh. Other studies confirm that the Indiana bat prefers larger trees (Gardner et al., 1991; Callahan et al., 1997; Kurta et al., 1996; Hobson and Holland, 1995; Kiser and Elliott, 1996; MacGregor et al., 1999). This could be due to the fact that larger the trees is have a higher probability that they could be dying or have exfoliating bark. GIS data from LANDFIRE (LANDFIRE.US_130EVH) was used to delineate trees of specific heights (Wildland Fire Science, 2013b). The EVH data consisted of land use data that incorporated average tree height measurements when labeling forested tracts of land. The EVH data was refined to the study area using the Clip Geoprocessing tool. Forested land with tree heights of over 5 meters were retained while all other data was removed from the GIS layer. These data were used as optimal habitat because of the positive correlation between forest height and the diameter of the trees present. The data was then converted from raster to polygon data using the Raster to Polygon Geoprocessing tool.

4. <u>Canopy closure: Between 20% and 50% canopy closure or 100% canopy closure within 30 meters of 0% canopy closure (Callahan et al., 1997; Rittenhouse, 2007; Dr. Carter, Personal Communication).</u>

Indiana bats choose roost trees that have some degree of solar exposure. The reasoning behind this preference could be the thermal advantages of raising young with increased solar radiation (Callahan et al., 1997; Menzel et al., 2001). To determine canopy closure, LANDFIRE data (LANDFIRE.US_130CC) was used (Wildand Fire Science, 2012). Less than 20% canopy closure would equate with lack of forested habitat and roost trees. Greater than 50% canopy closure would not allow the proper amount of solar radiation to penetrate and increase the temperature of the roost trees (Callahan et al., 1997). The canopy cover data was refined using the Geoprocessing Clip tool to extract the data within the study area. The forested habitats that had between 20-50% canopy closures were then selected and all other data was removed. The data was then converted form a raster to polygon data set. Indiana bats have also been found roosting in areas with up to 100% canopy closure if there are areas with 0% canopy closure within a close proximity that could be used as foraging habitat (Dr. Timothy Carter, Personal Communication). The habitat with 0% canopy closure was selected from the canopy cover data set. A buffer of 30 meters was created around these habitats using the Buffer Geoprocessing tool. Habitat with 80-100% forested habitat was then selected from the canopy closure data set. The Intersect Geoprocessing tool was used to determine when the two distinguished datasets overlapped. The data was also refined to the study area and converted from raster to polygon format as described above. The habitat with 20-50% canopy closure and the habitat that had 80-100% canopy closure that was within 30 meter of land with 0% canopy closure were combined using the Merge Geoprocessing tool.

5. Distance from anthropomorphic habitats: roads (impeding or travel corridors and distance from development (Berthinuseen and Altringam, 2012)

Indiana bats are known to avoid anthropomorphic habitat for several reasons. Roads are a source of mortality (Gaisler et al., 2009). The noise and lights from buildings and roads can impact communications between bats during night time foraging (Stone et al., 2009; Schaub et al., 2008; Siemers and Schaub, 2011). Pauli (2014) found increased Indiana bat activity near these anthropomorphic habitats. He attributed this relationship to the geography of the Hoosier National Forest. The closest major road (other than small service roads) was 400 meters away from any sampled location. This could mean that the bats were using the small scale roads for travel corridors between foraging and roosting habitat (Pauli, 2014). Two sets of data were used to classify anthropomorphic habitat, roads and developed land. Public roads were classified using polyline data (ROADS_2005_INDOT_IN: Indiana Roads from INDOT and TIGER Files, 2005 (INDOT, 1:100,000, Line Shapefile)). Roads with travel volumes less than 10 vehicles/5 min or 2 vehicles/min were considered travel corridors for foraging (Bennett et al. 2013). To determine the travel volume of each road in Randolph County, the metadata category CFCC (Census Feature Classification Code) was used for the INDOT GIS data. The CFCC values that would have the highest probability of having less than 2 cars/min travel volume were determine to be A51, A60, A64, A71 and A74 (Indiana Department of Transportation, Road Inventory Section 2016). These classified roads were added to the final habitat intersection as quality habitat defined as travel corridors for nighttime foraging. Roads with greater than 2 cars/min travel volume were considered a deterrent to bat movement. All other CFCC classified roads other than the ones listed previously were considered to have a travel volume high enough to impede and interfere with bat movement. A buffer of 2.5 meters was created around these roads

(Bennett and Zurcher, 2013) and this habitat was excluded from the final habitat model using the Erase Geoprocessing tool.

Distance to populated areas also has the potential to deter bat communities because of the lack of roost trees, high volume noise and vehicular impediments. LANDFIRE GIS (LANDFIRE.US_130EVC) data was used to classify high/medium/low intensity developed areas (Wildland Fire Science, 2013a). These areas were separated from the EVC data set and were combined using the Merge Geoprocessing tool. A 0.32 kilometer (approximately 0.2 miles) buffer was created around all high/medium/low intensity developed areas and this habitat was excluded from the final habitat model using the Erase Geoprocessing tool.

3.2.2 Habitat Model Creation

The variables above were defined separately to delineate specific habitat requirements for the Indiana bat. To determine where suitable habitat was found within Randolph County, all of the habitat requirements needed to be present. Using the Intersect Geoprocessing Tool, the variables below were processed to determine habitat that pertained all the habitat specialist requirements

1. Tracts of forested land between 20-60% forested
2. Less than 1000m away from a water source
3. Trees larger than 22 cm in dbh
4. Canopy closure between 20-50%.

Roads that could possibly be used as travel corridors were added to the habitat model using the Merge Geoprocessing Tool. As described, roosting habitat may be the limiting factor in the relationship between Indiana bat and their summer habitat (Pauli, 2013). Specific tracts of land were removed from the habitat model based on the possible negative impacts related to Indiana bat roosting. The anthropomorphic variables below were removed from the habitat model using the Erase Geoprocessing Tool.

1. Roads with greater than 2 cars/min traffic volume
2. Developed areas within close proximity to roosting habitat

3.3 Presence Only Verification

Data has been collected by the USFWS for the Indiana bat in various locations within Indiana. For species that are on the Endangered Species List, any capture or sighting of the species must be reported to the appropriate USFWS office. This data is compiled by species. If the data is collected by a natural resource professional or academic, the UTM X and UTM Y coordinates are recorded. Data has been collected for Randolph County for the Indiana bat from 1990 to 2015. A total of 52 Indiana bat locations have been recorded in Randolph County over the last 25 year period. This data will be considered our training data that is compared to the environmental variables described above. These bats were captured using traditional mist netting protocols by the USFWS through the Bloomington field office lead by Mr. Andrew King. These data were entered into the ArcGIS through formatting a spreadsheet into simplified x and y coordinates. The file was saved as a csv file that is compatible with ArcGIS. The data was assigned to the NAD_1983_UTM_Zone_16 projection, just as all of the other data layers. The criteria of comparing the presence locations to the habitat model were to have 100% of the presence locations fall within the designated habitat to validate the habitat variable assignments. Having all of the presence locations be located within the predicted habitat would show the strongest correlation between the predicted habitat variables and the presence of Indiana bats. Multiple trials will be conducted in which the habitat variables will be altered, in adherence with previous research, to create proposed habitat that encompasses all of the presence locations within Randolph County.

3.4 Habitat Model (Trial 1)

Trial 1 is the comparison of the presence locations for Randolph County and the habitat variables described above. Seven (13.46%) of the presence locations for Indiana bats collected by the USFWS in Randolph County were located within the proposed habitat model created with the variables described above. All of the presence locations were found within forested habitat within 1000 meters of a water source and outside of the detrimental anthropomorphic habitat. The limiting habitat variable in terms of presence locations found within the proposed habitat was canopy cover. A total of 86.54% of the presence locations were found with habitat with canopy closures > 50%, thus were outside the proposed habitat areas. All of the presence locations were within 20-80% canopy closure (Table 1). There were 23,589.85 acres of forested land, 1865.01 acres (7.91 %) of all forested land with between 20-50% canopy closures.

Table 1: The canopy closures of presence locations within Randolph County during Trial 1 of the habitat model creation

Canopy Cover	Presence Locations
10-20%	0 (0%)
20-30%	1 (1.92%)
30-40%	18 (34.61 %)
40-50%	1 (1.92%)
50-60%	2 (3.85%)
60-70%	14 (26.92%)
70-80%	16 (30.78%)
80-90%	0 (0%)
90-100%	0 (0%)

Direct sunlight has been found to be beneficial in terms of thermoregulation for raising young for Indiana bats (Humphrey et al., 1977; Kurta et al., 1993; Callahan et al., 1997; Britzke et al., 2003). Eight Indiana bat roost trees were found in Michigan in 1979 and all of the trees were in direct sunlight (Kurta et al., 1993). Gardner et al. found that in Illinois, 67% of Indiana bat roost trees found were in areas with greater than 80% canopy closure and were rarely found in habitat with less than 30% solar exposure. Gardner et al. (1991, pg ii) explained this as "roost sites exposed to intense solar radiation during midsummer may develop temperatures potentially lethal to *M. sodalis*". The difference in average summer (June, July and August) temperature for Michigan and Illinois is 6.5° F, 64.6° F and 71.1° F respectively (United States Weather Bureau 2002). With lower summer temperatures, Indiana bats in Michigan may choose roost trees with direct solar exposure to aid in thermoregulation for young. Adversely, roost trees in Illinois may have lower solar exposure due to the higher average temperatures in the summer and therefore need shaded roost areas to reduce overheating in summer months. The amount of solar exposure needed for Indiana bat in Indiana (with an average summer temperature of 69.9°) has not been documented (United States Weather Bureau, 2002). Therefore, canopy closure between 20-50% may be too narrow of a habitat variable for the Indiana bat in terms of median temperatures for their entire range. To revise the model, a canopy closure of 20-80% was delineated from the LANDFIRE.US_130CC data.

3.5 Habitat Model (Trial 2)

The habitat alterations described above in Trail 1 were incorporated into ArcGIS to determine if the current habitat model has the ability to encompass all of the presence locations within Randolph County. Forty (76.92%) of the presence locations for Indiana bats collected by the USFWS in Randolph County were located within the proposed habitat model created with the variables described above leaving a total of 23.08% out. Ten of the presence locations that were not located within the designated habitat were captured over open water. Open water habitat was excluded in the EVC (Existing Vegetative Cover) data when forested habitat (20-60%) was defined. To revise the model to apply the habitat points that were found within open water habitat, the open water habitat was included within the EVC data refinement. Indiana bats are known to forage in riparian habitats (Humphrey et al., 1977) as well as floodplain forests (Garner and Gardner, 1992). Murray and Kurta found that foraging habitat could consist of open water habitats such as portions of rivers (Murray and Kurta, 2004). Therefore this alteration is compatible with the Indiana bat habitat model because open water habitat can be used for foraging and therefore is a precursor for roosting habitat. The remaining 2 presence locations were located in 10-20% herbaceous cover. Herbaceous habitat was excluded in the EVC data when forested habitat (20-60%) was defined. To revise the model to apply the habitat points that were found within herbaceous habitat, the herbaceous habitat (10-20%) was included when comparing 80-100% forested habitat within a 100ft proximity of habitat with 0% canopy cover. Herbaceous land cover of only 10-20% could be considered similar to areas with 0% canopy cover. Indiana bats could potentially roost in habitat with 100% canopy closure if there are areas for foraging (less than 20% canopy cover) within a close enough proximity (Dr. Timothy Carter, Personal Communication). To modify the model, herbaceous habitat (10-20%) were included with the canopy covers of 0% (non-forested habitats) that were compared with forested habitats with 100% canopy closure within a proximity of 100ft. As described above, this alteration is compatible with the habitat map because of the similarity in use for foraging by the Indiana bat in terms of small amounts of herbaceous cover and 0% canopy cover. Trial 2 for the model creation encompassed 100% of the presence locations for Randolph County. The presence locations can be considered geographical markers for defining environmental variables (Table 2) that are consistent with quality roosting habitat. Therefore, the model can be said to be predictive of Indiana bat presence and can define quality summer roosting habitat for an agriculturally based landscape in northeastern United States.

Table 2: Habitat variables defined by model creation (100% of presence locations encompassed) within Randolph County, Indiana for the Indiana bat based on historic presence data

HABITAT VARIABLES
- Forested habitat of between 20% and 60%
- Existing Vegetative Height of 5 to 50 meters
- Canopy Closure between 20% and 80% or 100% canopy closure within 30 meters of 0% canopy closure
- Within 1000 meters of a permanent water source
- Not within 2.5 meters from a road with greater than 2 cars/min travel volume
- Not within 320 meters from a highly populated area

3.6 Statistical Analysis

It was important to determine if Indiana bats actually discriminate among habitat locations based on specific environmental factors considered relevant on an a priori basis. If this is true, mean habitat variable values will differ in sites that bats have been found in comparison to random locations or areas in which bats have not been found. The data collected by the USFWS that was used in the creation of the model using Randolph County (verified with Rush and Henry Counties) are presence-only data, which often show a non-normal distributions especially when abundances are low (Seavy et al., 2005). Therefore a generalized linear regression model was appropriate to determine if there was a relationship between habitat variables and the presence locations within Randolph County. Using ArcGIS, a two-way matrix of environmental data was constructed. Presence locations or observations were constructed as the rows and the environmental descriptors as columns. The environmental descriptors were data taken from ArcGIS that were able to be quantified based on the environmental variables used to construct the original habitat model (Table 2). The environmental descriptors used in the regression were, latitude, longitude, distance from permanent water source (meters), canopy closure (%), average forest height (meters), distance from impeding road (meters) and distance from highly developed areas (meters), as defined within the habitat model creation. These environmental descriptors were defined using a 30 meter by 30 meter cell size using the GIS data described in the creation of the habitat model. The number of presence locations allocated per x and y coordinate was considered minimum counts. Specifically, a Poisson regression was used to model the observed counts as Poisson random variables where counts were modeled as a function of the environmental descriptors. Multiple Poisson regressions were conducted in SPSS (Version 22) in a stepwise function using a subset of the environmental descriptors (IMB 2013). The response variable was related to the covariates with the equation

$$\ln(\mu) = B + \beta(x),$$

where x was the matrix of covariate values, β was a vector of unstandardized coefficients and *B* was the intercept. A total of 5 candidate models were ran: (1) intersect, distance from water, canopy closure and distance to development, (2) longitude, latitude, distance from water, canopy closure, forest height, distance form impeding road and distance from development, (3) longitude, distance from water, canopy closure, forest height, distance from impeding road and distance from development, (4) longitude, distance from water, canopy closure, forest height, distance from development, (5) longitude, distance from water, canopy closure and distance from development. The models were selected by first running the model with all five habitat variables, followed by running the models with habitat variables found to be significant in the previous models. This method provided the ability to look for variation in the dependent variable based on the specific inclusion of the independent variables (see Appendix, Table 13). To determine which model fit the data the best, AIC (Akaike Information Criterion) values were compared (lower the AIC, the better the model fit the data). The finalization of the model creation provided number of bats per 30m by 30m area when knowing the environmental descriptors for a specific location.

3.7 Habitat Model Verification using Rush and Henry Counties Presence Locations

To validate the habitat model that was created using presence locations of Indiana bats found in Randolph County, a test data set of presence locations can be compared to the model. The presence locations of Indiana bats found with Randolph County are the data that trained the original model creation. The presence locations of Indiana bats found within Rush and Henry Counties are the data that tested the validity of the model. There were adequate presence locations within the two counties to validate the model. Also, Henry and Rush Counties are within close proximity to Randolph County and have similar agriculturally based landscapes. There were 43 presence locations within Rush and Henry Counties. These presence locations were saved as a csv file and were added into a new map within ArcMap. The habitat variables described below in Table 3 were used to manipulate the GIS data to determine the locations of tracts of forested land that could boast Indiana bat populations. Tracts of forested land with the specific habitat variables found within the creation of the GIS habitat model were applied to

Rush and Henry Counties using the same data manipulation and geoprocessing as in the creation of the model within Randolph County (see sections 3.2-3.4 pg. 25-31). Under the assumption that the habitat model created accurately depicts Indiana bat habitat in an agriculturally based landscape within the northeastern United States, all of the presence locations within Rush and Henry County should be encompassed within the habitat depicted.

Table 3: Habitat variables that were applied to Henry and Rush Counties and the Geoprocessing Tools associated with the application

Habitat Variables	Geoprocessing Tools
-Forested habitat between 20-60%	Raster Clip, Raster to Polygon
-Existing Vegetative Height of 5 to 50 meters	
-Canopy Closure between 20% and 80% or 100% canopy closure within 30 meters of 0% canopy closure	Raster Clip, Raster to Polygon, Buffer, Intersect, Merge
-Within 1000 meters to a permanent water source	Clip, Merge, Buffer
-Not within 2.5 meters from a road with greater than 2 cars/min travel volume	Clip, Buffer, Erase
-Not within 320 meters from a highly populated area	Clip, Buffer, Erase

Chapter 4: Results

4.1 ArcGIS Habitat Model Creation, Randolph County

A total of 52 presence locations were used for Randolph County for the creation of the Indiana bat habitat model. Of the 52 bat locations observed there were 8 males, 44 females, 4 juveniles and 48 adults. The range of mass for the bats was between 6.9 and 10 grams with an average mass of 7.99 grams (standard deviation of 0.92). The range for the forearm length for the bats was between 35.5 and 41 mm. with an average forearm length of 38.12 mm. (standard deviation of 1.29).

The model created in Randolph County (Figure 6) depicted a total of 18,797.59 acres of Indiana bat habitat based on the presence locations described above. The variables that described 100% of the presence locations were created by the habitat variables described in Table 2. Of the acres of Indiana bat habitat depicted in Randolph County, the range of distance from water for the presence locations was 1.16 to 200.18 meters (mean = 79.10, SD = 90.57). The types of open water bodies that were within the closest proximity to the presence locations were freshwater forested/shrub wetlands and freshwater emergent wetland. A freshwater forested/shrub wetland was defined by the USFWS as a forested swamp or wetland shrub bog or wetland (Palustrine forested and/or Palustrine shrub) (U.S. Geological Survey and the U.S. Environmental Protection Agency, 2008). A freshwater emergent wetland was defined as herbaceous marsh, fen, swale and wet meadow (Palustrine emergent) (U.S. Geological Survey and the U.S. Environmental Protection Agency, 2016).

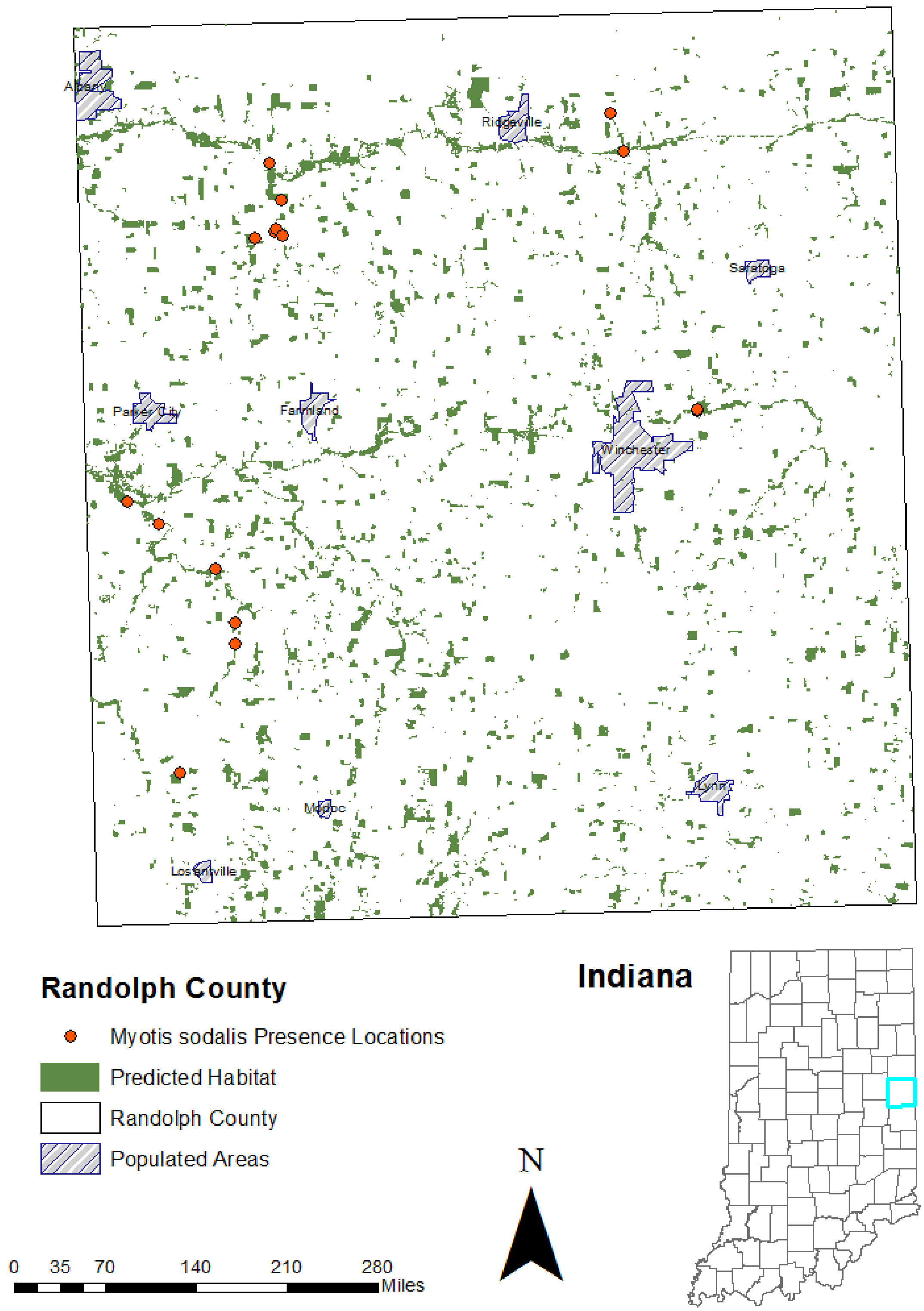

Figure 6: Predicted habitat model for the Indiana bat in Randolph County, Indiana based on the habitat model creation

The river and creek systems that were in the closest proximity to the presence locations were Bush Creek, Mississinewa River, Elkhorn Creek, O-Brien Creek, Stoney Creek, Little White River and White River. Over 61% of the Indiana bat habitat depicted by the model had 70% to 80% canopy cover (Table 4).

Table 4: Amount of each type of canopy closure within predicted habitat for the Indiana bat in Randolph County, Indiana

Canopy Closure	m^2	Acres	Percentage of Habitat
20-30%	251744	62.18	0.19
30-40%	1620710	400.31	1.23
40-50%	7793951	1925.10	5.90
50-60%	9775376	2414.51	7.40
60-70%	22767421	5623.55	17.24
70-80%	81240117	20066.31	61.52

There were 376.87 acres of habitat with 100% canopy closure within a 100ft to land with 0% canopy cover. A total of 15,126.56 acres (80.47%) of the Indiana bat habitat depicted by the model had average forest heights between 10 and 25 meters. Only 19.52% (3669.27 acres) of the habitat depicted had an average forest height of 25 to 50 and 0.0093% (1.75 acres) of the habitat had an average forest height of 5-10 meters. There were 2,861.43 meters of roads were found to have a travel volume of less than 2 cars per minute (Bennett et al. 2013) and were added to the overall habitat model in terms of travel corridors. There were 1,285.52 meters of roads that were found to have travel volumes of greater than 2 cars per minute within the proposed habitat and 1.64 acres of land that was excluded from the habitat model in terms of a 2.5 meter buffer on both sides of the impeding road. A total of 1,221.59 acres were removed from the habitat model in terms of the 0.2 mile buffer created around the high intensity developed areas that would impede Indiana bat roosting.

4.2 Statistical Analysis of Habitat Model, Randolph County

In total there were 52 presence locations dispersed over 16 unique geographical coordinates that were used in the creation of the environmental variables matrix that was analyzed using Poisson Regression (Figure 7). The first phase of interpreting results from a generalized linear model (Poisson regression) was to determine if there was overdispersion in the data. Overdispersion refers to more variability in the data than is assumed under the given statistical models' distribution (Berk and MacDonald, 2008). To determine if the statistical models were overdispersed, the residual deviance should be approximately equal to the residual degrees of freedom (Agrestic 1996). For the five models conducted, model 1 was not significantly overdispersed, therefore the model could be interpreted for its validity to predict species per habitat variables (Table 5). Models 2 through 5 were slightly underdispersed, which means that the deviance is less than the degrees of freedom, which is a cause for concern in terms of the distribution of the environmental variables. Some causes of underdispersion, as well as overdispersion, could be variability in experimental material, correlation between individual responses, aggregate level data, omitted unobserved variables or excess zero counts (Berk and MacDonald, 2008). Models 2 through 5 were slightly

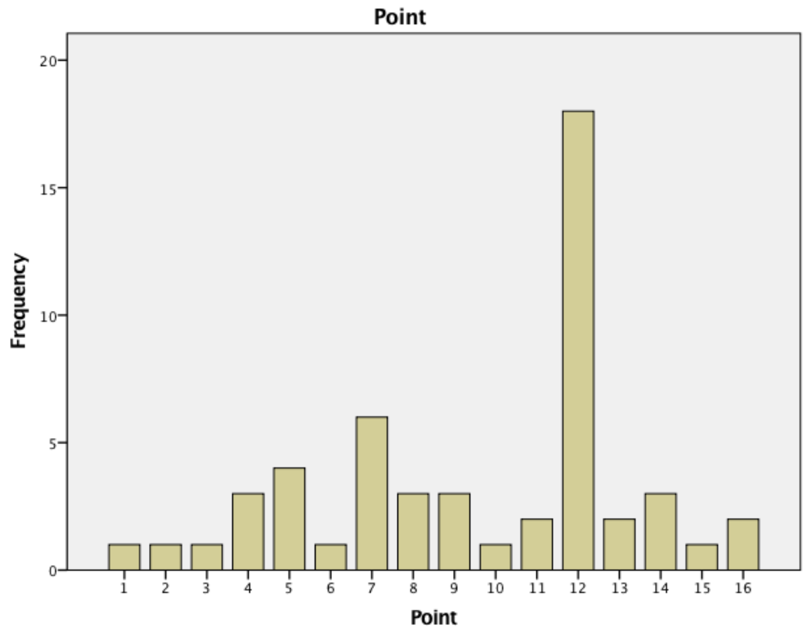

Figure 7: Histogram of the frequency of presence locations within Randolph County, Indiana used in the creation of the habitat model for the Indiana bat

underdispersed, but with no strict cut off values for overdispersion and underdispersion in terms of comparing deviance and df, the values were defined as not significantly underdispersed. An omnibus test, a form of a likelihood-ratio chi-square test was performed to determine how the current model compares to the null (intercept) model. All of the five models significantly outperformed the null model in predicting habitat components based on Indiana bat presence locations (see Table 13 in Appendix).

When interpreting the significance of each environmental variable on the performance of the model, models 2, 3 and 4 did not have all environmental variables show significance in terms of predicting habitat for the species (see Table 13 in Appendix). Model 2 (environmental variables: distance from water, canopy closure, forest height, distance form impeding road, and distance form development) showed only distance from development as statistically significant ($F_{1, 44} = 37.80$, $P = 0 .016$). Model 3 (environmental variables: distance from water, canopy closure, forest height, distance from impeding road and distance from development) also showed only one statistically significant habitat variable, distance from development ($F_{1, 45} = 38.554$, $P < 0.01$). Model 4 (environmental variables: distance from water, canopy closure, forest height, distance from development) showed three statistically significant variables, distance from water ($F_{1, 46} = 39.973$, $P=0.014$), canopy closure ($F_{1, 46} = 39.973$, $P = 0.019$), and distance from development ($F_{1, 46} = 39.973$, $P < 0.01$). Model 1 (environmental variables: distance form water, distance form development and canopy closure) showed all variables statistically significant to the model ($F_{1, 48} = 48.245$, $P = 0.001$; $F_{1, 48} = 48.245$, $P = 0.009$; $F_{1, 48} = 48.245$, $P = 0.006$, respectively). Model 5 (environmental variables: distance form water, distance from development and canopy closure) also showed all variables statistically significant to the model ($F_{1, 47} = 40.503$, $P=0.012$; $F_{1, 47} = 40.503$, $P = 0.012$; $F_{1, 47} = 40.503$, $P = 0.028$; $F_{1, 47} = 40.503$, P

< 0.01, respectively). An information-theoretic approach was used in model selection using AIC to select the model that fit the data the best (Spiegelhalter et al., 2002). Model 1 had the lowest AIC score (-1292.973, sd =2.16) as well as habitat variables showing statistical significance in the overall model (Table 5).

Table 5: Deviance and AIC scores for the five multiple Poisson regression models conducted to analyze the validity of environmental variables used in habitat model creation for the Indiana bat in Randolph County, Indiana

Model	Deviance	Df	Deviance/df	AIC	p
1	48.245	48	1.005	-1292.97	<0.001
2	37.8	44	0.859	-1295.42	<0.001
3	38.554	45	0.857	-1296.66	<0.001
4	39.973	46	0.869	-1297.25	<0.001
5	40.503	47	0.862	-1298.72	<0.001

Model 1 was used as the statistical model for the predictive habitat. The parameter estimates table summarizes the effects of each predictor variable on the overall model. The unstandardized coefficient (β) gives insight into the negative or positive impacts of the variables as well as relative impact of the variables on the statistical model. In terms of statistical model 1, an increase of one Indiana bat per 900 m^2 area would substantiate an increased distance from water of 0.005 meters, an increased distance from development of 0.00008 meters from the presence location and an increased canopy closure of 2.1% at the presence location. The predicted habitat equation created by statistical model 1 is as follows:

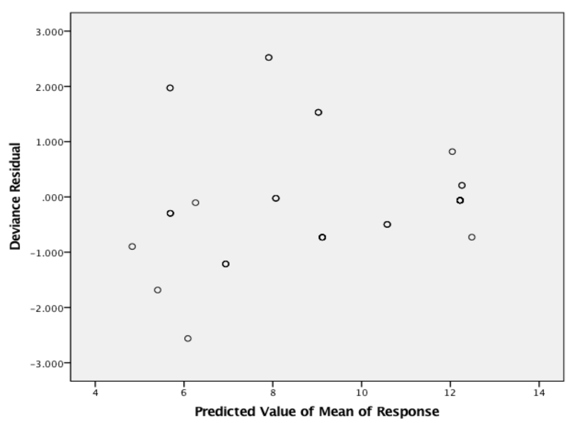

Figure 8: Plot of the residual deviance and the predicted value of the response based on the statistical model equation by statistical model 1

$\ln(\hat{\mu}) = 0.146 + 0.005$ (Distance from water) $+ 0.021$ (Canopy Closure) $+ 0.00008$ (Distance from development).

4.3 Habitat Model Verification using Rush and Henry Counties

The model was verified using test data from Rush and Henry Counties. There were a total of 43 amount of presence locations between Rush and Henry Counties for Myotis sodalis, 21 and 22 respectively. Of the 43 bat presence locations, 13 were male, 30 were female and 16 were juvenile and 27 were adults. The range of mass for the bats was between 5.5 and 9.4 grams with an average mass of 7.02 grams (standard deviation of 1.04). The range for the forearm length of the bats was between 36 and 42mm with an average forearm length of 37.56 mm (standard deviation of 1.32).

Of the 43 amount of bat presence locations, 42 (97.67%) were found within the habitat delineated by the habitat model created. The applied model depicted a total of 40677.90 acres of Indiana bat habitat (Figure 9). Of the acres of Indiana bat habitat depicted in Rush and Henry Counties combined, the range distance from water for the presence locations was 1.56 to 71.75 meters (mean = 13.08, SD = 14.04). The types of water sources that were within the closest proximity to the presence locations were freshwater forested/shrub wetlands and freshwater ponds. Freshwater forested/shrub wetland was defined above in the results section for Randolph County. A freshwater pond was defined as a pond with Palustrine unconsolidated bed (U.S. Geological Survey and the U.S. Environmental Protection Agency 2-16). The river and creek systems that were in the closest proximity to the presence locations were Harrigan Branch, Ben Davis Creek, Flatrock River, Wikoff itch, Shawnee Creek, Big Blue River, Circle run, Montgomery Creek, Buck Creek, Roy Run and little Blue River.

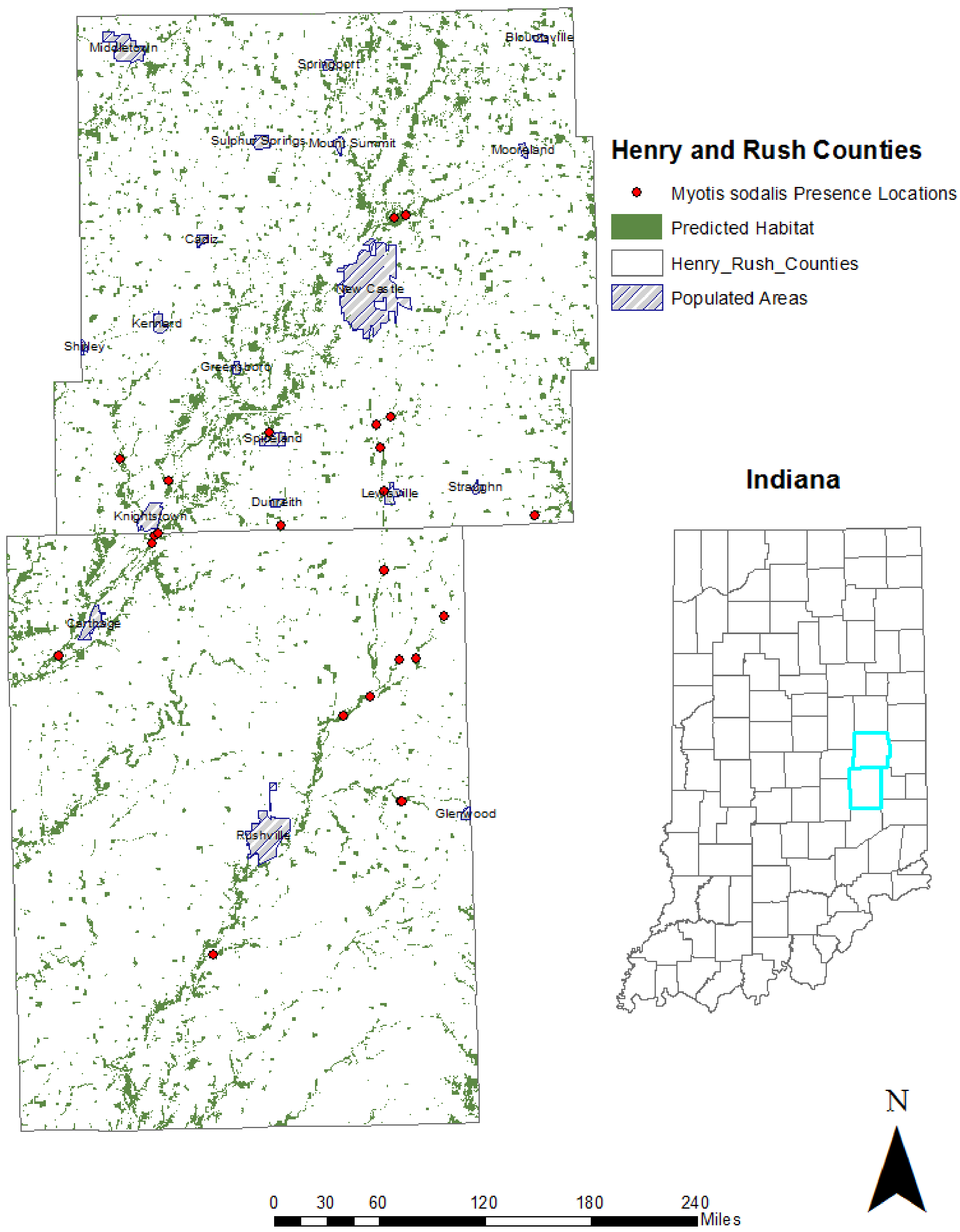

Figure 9: Predicted habitat model for the Indiana bat in Henry and Rush Counties, Indiana based on habitat model creation

Over 57.83% of the Indiana bat habitat depicted by the model has between 70-80% canopy covers (Table 6).

Table 6: Canopy Closures of predicted habitat within Rush and Henry Counties, Indiana for the Indiana bat

Canopy Closure	m^2	Acres	Percent of Habitat
20-30%	382273.06	94.42	0.23
30-40%	1723796.08	425.78	1.05
40-50%	6514884.89	1609.18	3.96
50-60%	13059491.04	3225.69	7.93
60-70%	31227486.92	7713.19	18.96
70-80%	95233575.85	23522.69	57.83

There were 1442.19 acres of habitat with 100 % canopy closure and within 100ft to land with 0% canopy closure. 76.77% of the Indiana bat habitat depicted by the model had an average forest height between 10 and 25 meters. Only 0.07% of the habitat depicted had an average forest height of 5 to 10 meters (Table 7).

Table 7: Average forest height of the predicted habitat within Rush and Henry Counties, Indiana for the Indiana bat

Average Forest Height (m)	m^2	Acres	Percentage of Habitat
5-10	118716	29.32	0.07
10-25	126373563	31214.27	73.14
25-50	44441288	10981.01	25.72

A total of 2277 meters of roads were found to have a travel volume of less than 2 cars per minute (Bennett et al. 2013) and were added to the overall habitat model in terms of travel corridors. There were 3591 meters of roads that were found to have travel volumes of greater than 2 cars per minute and 4.45 acres of land that were excluded from the depicted habitat in terms of a 2.5 meter buffer on both sides of the impeding road. A total of 2133 acres were removed from the depicted habitat in terms of the 0.2 mile buffer created around high intensity developed areas that would impede Indiana bat roosting.

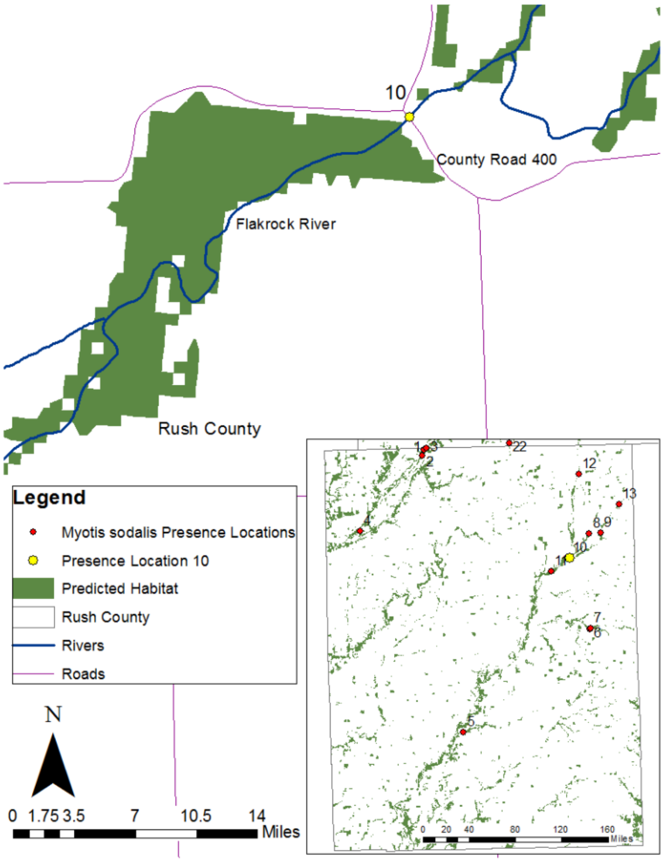

Figure 10: Single presence location within Rush County that did not fall within the predicted habitat for the Indiana bat when testing the habitat model

The one presence location that was not within the predicted habitat was located 23.11 meters from a predicted habitat corridor that stretched approximately 6.07 miles northeast to southwest within forested habitat along the Flatrock River (Figure 10). It was located within NASS (National Agricultural Statistics Service) row crop and was 3.25 meters from what was defined as an impeding road (County Road 400 North within Rush County).

The impeding road within close proximity to the presence location was defined by CFCC code A41 which is defined as a "local, neighborhood, and rural road, city street, unseparated". This road seems to have separated the stretch of forested habitat that follows along Flatrock River. When defining impeding roads and roads that can be used as travel corridors, there were a few roads that were not defined properly by CFCC codes. County Road 400 is a road that could be defined as a travel corridor between habitats during the day or as a foraging habitat during the night. This presence location fell within such a close proximity to multiple predicted habitat fragments as well as within less than 4 meters from what could have been defined as a travel corridor, that it does not negate the validity of the overall model.

4.4 Application to Madison and Delaware Counties, Indiana

The model that was created using Randolph County, that encompassed 100% of the presence locations within the county and was verified using test data from Rush and Henry Counties as well as Poisson regression, was applied to Madison and Delaware Counties. Overall there were 14987.02 acres (60650237 m^2) and 17629.25 acres (71343041.31 m^2) of Indiana bat habitat within Madison and Delaware Counties that encompassed 5.17%, 6.96% of the land area for each county, respectively (Figure 11). The open water lakes that were within close proximity to predicted habitat were Burlington Lake, Emerald Lake, Jackson Lake, Jim Lake, Phillips Lake and Prairie Creek Reservoir. The wetland water sources that were found within the closest proximity to the proposed habitat were freshwater emergent wetland and freshwater forested/shrub wetland (defined above in Application to Rush and Henry Counties).

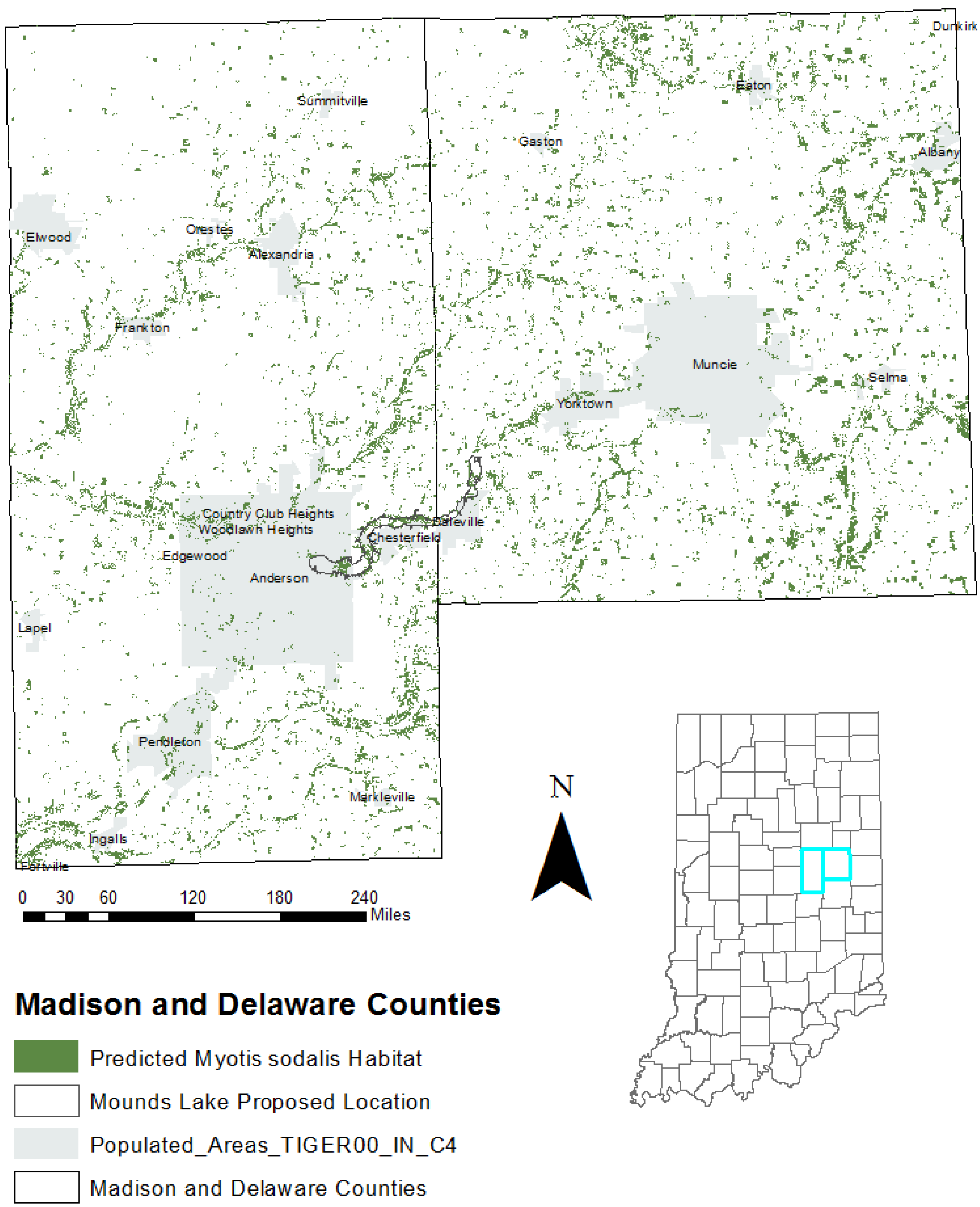

Figure 11: Predicted habitat model for the Indiana bat in Madison and Delaware Counties, Indiana based on habitat model creation

The most prevalent canopy closure was between 70 and 80% (61.52% of the total proposed habitat) and the least prevalent was between 20 and 30% (0.19%) (Table 8).

Table 8: Canopy closures for predicted habitat of the Indiana bat within Madison and Delaware Counties, Indiana

Canopy Closure	m^2	Acres	Percentage of Habitat
20-30%	251744	62.18	0.19
30-40%	1620710	400.32	1.23
40-50%	7793951	1925.11	5.90
50-60%	9775376	2414.52	7.40
60-70%	22767421	5623.55	17.24
70-80%	81240117	20066.31	61.52

There were 3478.97 acres (14078899 m^2) of habitat with 100% canopy closure that were within 100ft of land with 0% canopy closure. The most common forest height (Table 9) was between 10 and 25 meters (84.69% of the total predicted habitat).

Table 9: Forest heights for the predicted habitat of the Indiana bat within Madison and Delaware Counties, Indiana

Average Forest Height (m)	m^2	Acres	Percentage of Habitat
5-10	3350.01	0.827452	0.002536919
10-25	111835186	27623.29	84.69133806
25-50	22397418	5532.162	16.96127473

A total of 2124.21 meters of roads were found to have a travel volume of less than 2 cars per minute (Bennett et al. 2013) and were added to the overall habitat prediction in terms of travel corridors. There were 3857 meters of roads that were found to have greater than 2 cars per minute and 4.77 acres of land that were excluded from the depicted habitat in terms of the 2.5 meter buffer on both sides of the impeding roads. A total of 1600.61 acres were removed from the depicted habitat in terms of the 0.2 mile buffer created around high intensity developed areas that would impede Indiana bat roosting.

One of the most prevalent developmental projects proposed within Madison and Delaware Counties is the Mounds Lake Reservoir. The overall reservoir could potentially encompass 1835.8 acres of land surface within Madison and Delaware Counties. The habitat model that was applied to Madison and Delaware Counties was refined using the Clip and Dissolve Geoprocessing Tools to delineate Indiana bat habitat within the proposed location of the reservoir. The applied model within the proposed reservoir defined 567.40 acres of Indiana bat habitat that comprised 30.91% of the total surface area of the reservoir (Figure 12). The major water source that perpetrated the delineation of the habitat is the White River. The tracts of forested land that are encompassed as proposed habitat are Mounds Lake Reservoir, Rangeline Nature Preserve and other tracts of forested land along the White River. The majority of the habitat within the proposed habitat has a canopy closure of 70 to 80% (48.71%) and an average forest height of 10 to 25 meters (61.87%), see table 10 and 11.

Table 10: Canopy closures within the predicted Indiana bat habitat for the Indiana bat within the proposed location of the Mounds Lake Reservoir

Canopy Closure	m^2	Acres	Percent of Habitat
20-30%	4487.54	1.108422	0.195351
30-40%	184104.7	45.47385	8.014426
40-50%	158479.5	39.14443	6.898912
50-60%	136930.3	33.82179	5.960838
60-70%	610279.5	150.739	26.56663
70-80%	1119037	276.4022	48.71382

Table 11: Forest heights within the predicted Indiana bat habitat for the Indiana bat within the proposed location of the Mounds Lake Reservoir

Forest Height	m^2	Acres	Percent of Habitat
5-10	159.456	0.039386	0.006941
10-25	1421351	351.0738	61.87412
25-50	854377.6	211.0313	37.19268

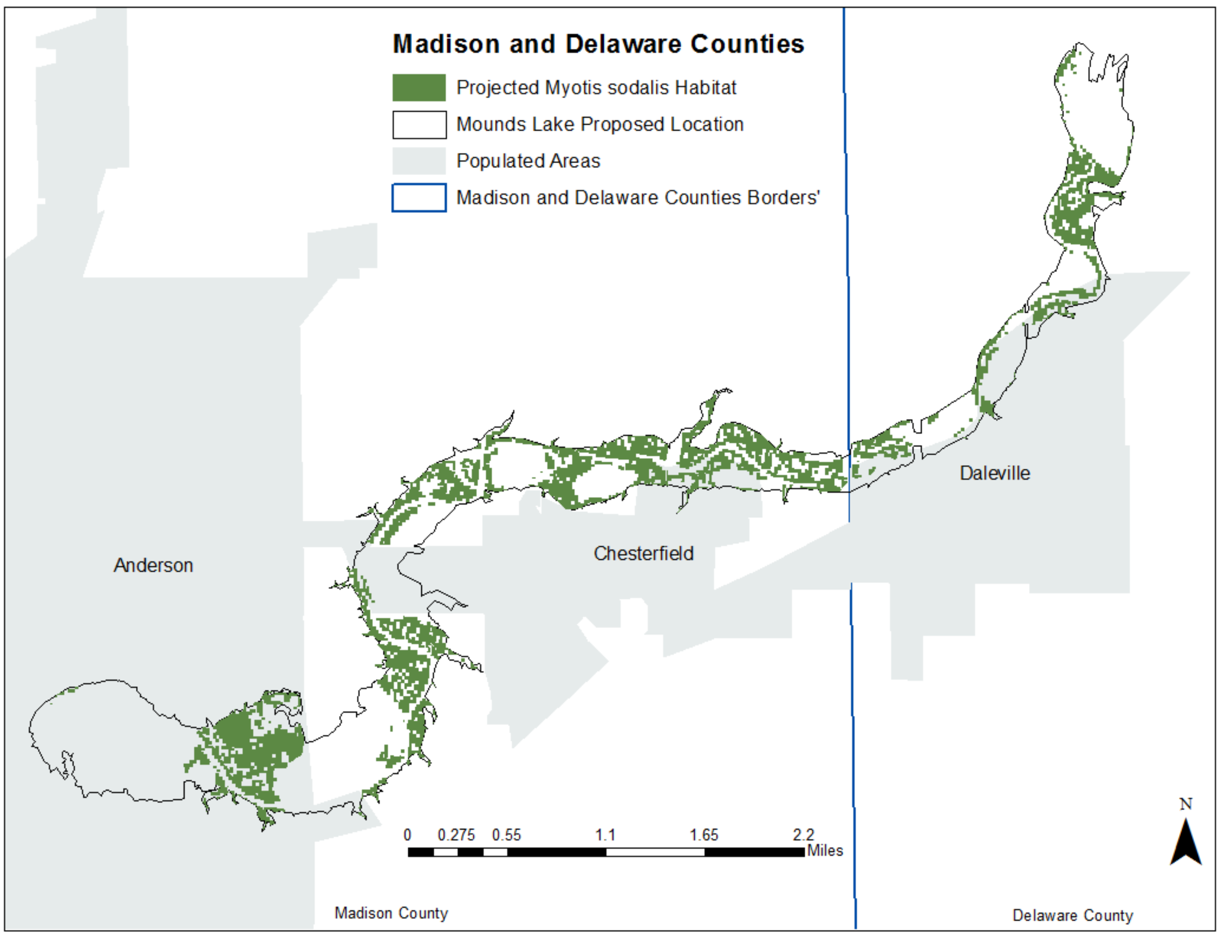

Figure 12: Predicted habitat model for the Indiana bat in Madison and Delaware Counties, Indiana based on habitat model creation within the proposed location of the Mounds Lake Reservoir Project

Chapter 5: Discussion

The ArcGIS model created for the summer roosting habitat for the Indiana bat was successful in predicting critical habitat for the endangered species within central Indiana. The model was successfully verified using a twofold approach. The first step of model verification was using a set of test data (separate from the training data from Randolph County) to determine the validity of the model created. The training data (Randolph County) used to create the GIS based model only required two Trials to encompass 100% of the presence locations within the county. This gives insight into the validity of the previous research and the knowledge of Indiana bat professionals in terms of the understanding of the requirements for the species. The test data (Henry and Rush Counties) was able to encompass 97.67% of the presence locations within these counties. Having all but one presence locations fall within the predicted habitat for the test data defines a valid model under the predictive power of the model. The model was then statistically analyzed using multiple Poisson Regressions which determined that three of the five habitat variables (canopy closure (%), distance from a water source and distance from development) were found to be statistically significant in determining the presence of Indiana bats within the proposed landscape. The other two habitat variables, distance from roads and forest height were not found to be statistically significant in the three regressions in which they were included. The statistical significance of these two habitat variables may illustrate a correlation between multiple habitat variables and therefore not necessarily preclude their importance in determining the presence of the species. Using historic presence locations for an elusive species, specific habitat variables were found to have significant importance in determining the presence of the species (Table 12).

Table 12: Environmental variables depicted by creation of habitat model for the Indiana bat within the eastern Corn Belt landscape

HABITAT VARIABLES
- Tracts of forested land between 20% and 60%
- Existing Vegetative Height of 5 to 50 meters
- Canopy Closure between 20% and 80% or 100% canopy closure within 30 meters of 0% canopy closure
- Within 1000 meters from a permanent water source
- Not within 2.5 meters from a road with greater than 2 cars/min travel volume
- Not within 320 meters from a highly populated area

5.1 Canopy Closure

Overall, canopy closure was statistically significant in terms of predicting Indiana bat presence within our landscape ($F_{1,48} = 49.245$, $P = 0.009$). The variable was also statically significant in all of the four remaining models (Table 5). The first statistical model predicted that there would be a statically significant (in terms of each habitat variables) relationship between canopy closure, distance from water and distance from development in terms of the amount of Indiana bats found at a particular location ($\ln(\hat{\mu}) = 0.146 + 0.005$ (Distance from water) $+ 0.021$ (Canopy Closure) $+ 0.00008$ (Distance from development)). The canopy closures that were added into the original model (Trial 1) were between 20-50%. With these delineations only 13.46% of the presence locations within Randolph County fell within the proposed habitat. Therefore, in Trial 2, canopy closures between 20-80% were used to delineate Indiana bat habitat. There have been positive correlations found between increased canopy cover and presence of Indiana bat in previous studies (La Val et al., 1977). This has been attributed to the fact that at Indiana bat roost sites, young are raised during the summer months. During these months when the temperatures are at their highest, increased amount of solar protection are needed to protect young from overheating at the roost tree. A completely closed canopy has the potential to have the opposite effect on the young in that during the coldest parts of their summer roost, they may not be able to thermoregulate due to the lack of any solar exposure (Humphrey et al., 1977; Kurta et al., 1993; Callahan et al., 1997; Britzke et al., 2003). Overall there was a strong correlation between canopy closures between 20 and 80% and the presence of Indiana bats in conjunction with other relating habitat variables.

5.2 Distance from Water

Indiana bats require close proximity to a water source for optimal roosting (Brack, 1998; Carter, 2006). This is because they require water sources for drinking purposes and also use the open canopy above these water sources for foraging (Bergeson et al., 2013). When creating the original model, a distance of 1000 m away from a water source was defined as optimal. This did not change during the two Trials conducted creating the map within Randolph County. During Trial 2 of the model creation, open water habitat was included in the overall model when only 76.92% of the presence locations were encompassed within the proposed habitat after Trial 1. Indiana bats have been found to forage over open water (Callahan et al., 1997). The basis of the habitat model creation at the beginning was that roosting habitat requires much more specific habitat requirements and therefore could be seen as a prerequisite for foraging habitat if there was open canopy land area within a close enough proximity, which was included when defining canopy closures as low as 20% as well as when looking at canopy closures of 100% within a 30 meter proximity of 0% canopy closures. Three out of the five statistical models that were performed found that distance from water was statistically significant in determining the presence of Indiana bats within the landscape ($F_{1,48}$ = 48.245, p = 0.001, $F_{1,46}$ = 39.973, p =0.014, $F_{1,47}$ = 40.503, p=0.012). Statistical models 2 and 3 did not show statistical significance in terms of distance from a water source being able to predict the presence of the Indiana bat. These models both included all five habitat variables as well as coordinates for each presence location. The only habitat variable that was shown to be significant in each of these two models was the distance from development ($F_{1, 44} = 37.8$, $p = 0.016$; $F_{1, 45} – 38.554$, $p < 0.001$). Distance from an impeding road was used as an environmental variable in two of the five models (the two models that did not show that distance from a water source was statistically significant) and was not found significant in either of these models ($F_{1, 44} = 37.8$, $p = 0.119$; $F_{1, 45} = 38.554$, $p = 0.192$). There is possibility that distance from water and distance from an impeding road may be closely correlated and therefore are causing interference in the statistical significance of the environmental variable, distance from water. Therefore the presence of the environmental variable, distance from impeding road may have had an impact on the overall importance and statistical significance of the other environmental variables and may be causing multicolinearity of these independent variables. When this environmental variable is removed from the other three statistical models, the environmental variable, distance from water becomes statically significant. Distance from a water source should be seen as a pertinent environmental variable in terms of summer roosting habitat for the Indiana bat.

5.3 Distance from Impeding Road

When creating the habitat model the habitat variable, distance from impeding road, did not change during Trial 1 or Trial 2. When removing the habitat within the close proximity to roads with travel volumes higher than 2 cars/min, none of the presence locations were impacted for the training data (Randolph County) and only impacts a single presence location in the test data (Henry and Rush Counties). This gives insight into the fact that Indiana bats are not roosting near roads with high travel volumes. This could be due to noise and light that impacts their nightly foraging or daily roosting as well as vehicular traffic that is threatening as they travel across these roads to move from their roosting habitat to their foraging habitat (Berthinussen and Altringham, 2012). Artificial lighting can affect bats commuting from foraging to roosting habitat (Stone et al., 2009) as well as the noise from these roads can impact bats echolocation (Schaub et al., 2008; Siemers and Schaub, 2011). Roads also cause direct mortality due to collisions for traveling bats (Gaisler et al., 2009; Russell et al., 2009). Two of the five models were conducted with distance from an impeding road as an environmental variable. For both of these models, distance from an impeding road was not found to be statically significant in determining presence of Indiana bats ($F_{1, 44} = 37.8$, $p = 0.119$; $F_{1, 45} = 38.554$, $p = 0.192$). When examining where the presence locations are located within the landscape, all of the presence locations were within forested habitats that are not within close proximity to roads with high travel volumes. When the model was created, only 1.64 acres of land was removed from the habitat model in Randolph County when excluding habitat within a 2.5 meter distance from roads with a travel volume of higher than 2 cars/min. When verifying the model using data from Rush and Henry Counties, only 4.45 acres of land was removed that would impact Indiana bat roosting due to high travel volume roads. Therefore, when creating a Poisson Regression to fit the data with the environmental variable, distance from impeding road was not statistically significant because the variable correlated with the landuse in which the bats were roosting. Highly forested areas with high canopy closures within close proximity to water sources relates to not being in a close proximity to roads with high travel volumes, which is evident by the small amount of habitat that was found within close proximity to these roads within three counties in Indiana.

5.4 Forest Height

Forest height was included in two of the five Poisson regressions. It was not found to be significant in either of the two models ($F_{1, 44}$ = 37.8, p = 0.119; $F_{1, 45}$ = 38.554, p= 0.192). In terms of forest height, the understanding of the variable is important in understanding its significance in the statistical models. The most descriptive forest height GIS data that is available without sampling is the LandFire data used in the study. The LandFire data defines the forest heights into three categories, 5-10, 10-25, and 25-50 meters. Anything over 5 meters in height has the potential to have cavities and exfoliating bark which can be used as roosting habitat. Previous studies have concluded that trees larger than 22 cm in dbh have the highest potential to boast Indiana bats (Kurta et al., 2002; Lacki et al., 2009). When creating the habitat model, forest height data was used to correlate to possible dbh of the trees within the landscape. The taller than stand of trees, the higher probability they will be greater than 22 cm dbh and therefore would have a higher probability of having exfoliating bark or cavities used for roosting.

5.5 Distance from Development

When creating the habitat model the environmental variable, distance from development was not altered during Trial 1 or Trial 2. None of the presence locations within the training data (Randolph County) or the test data (Henry and Rush Counties) were found within the 0.32 kilometer buffer around highly populated areas. Indiana bats within three counties in Indiana, based on historic data, have not been found selecting roost sites within a close proximity to highly populated area. Similar reasoning can explain the lack of Indiana bats roosting close to highly populated areas as can be said for roads with high travel volumes. Highly populated areas have large amount of light and noise pollution that can cause disturbance to bats roosting during the day as well as hinder their ability to find safe foraging habitat during their nocturnal hours. Conversely, large amounts of habitat were removed from the habitat model in terms of the 0.32 kilometers buffer that was created around highly populated areas. Within the training data, 1221 acres of land was removed and within the test data, 2113 acres was removed from the predicted habitat. Therefore, there may be forested fragments with high canopy cover and within a close proximity to water sources that may not boast Indiana bat roosts due to the disturbances caused by the highly developed areas. The environmental variable, distance from development was included in all five of the statistical models and was found to be statistically significant in all of the models ($F_{1, 48} = 48.245$, $p = 0.006$; $F_{1, 44} = 37.80$, $p = 0.016$; $F_{1, 45} = 38.554$, $p < 0.001$; $F_{1, 46} = 39.973$, $p < 0.001$, $F_{1, 47} = 40.503$, $p < 0.001$). The environmental variable being found to be statistically significant correlates with the large amount of forested land removed from the predicted habitat model. There are tracts of forested land that provide adequate canopy closure, proximity to water and roost tree selection (size correlating to cavities and exfoliating bark) that are within too close of a proximity to highly developed areas to be utilized by Indiana bats for their roosting habitat. These results agree with previous research that human development has the potential to negatively impact the probability of Indiana bat roosts (Carter et al. 2002).

5.6 Application to Madison and Delaware Counties

The model with the specific habitat variables described in table 12 was applied to Madison and Delaware County. There were approximately 14987.02 acres and 17629.25 acres of Indiana bat habitat delineated within Madison and Delaware Counties, respectively. The model was also applied to the proposed location for the Mounds Lake Reservoir. There was approximately 567.40 acres of Indiana bat habitat delineated, 30.91% of the total land area of the proposed location of the reservoir. A large portion of the land area for the proposed reservoir will have the potential to boast an endangered species. Summer habitat requirements for the Indiana bat are currently being studied as a way to protect the endangered species. The Indiana bat is a habitat specialist and therefore requires multiple specific habitat requirements for both their roosting and foraging habitat. Even with efforts to protect Indiana bats from White Nose Syndrome as well as hibernacula loss for the last 40 years the species is still declining (Callahan et al. 1997, Kurta and Whitaker 1998). This could be partly due to the loss and fragmentation of forested land that is required by the species for their summer roosting. Inundating over 567 acres of land that has the potential to be prime Indiana bat summer roosting habitat has the potential to negatively impact a federally endangered species with multiple causes for their decline.

Chapter 6: Conclusion

The focus of this research was to determine the amount of suitable Indiana bat habitat for a federally endangered species in terms of possible development within Madison and Delaware Counties. Development project committees will have to consult with the USFWS to determine if there are sustainable threats to endangered or threated wildlife within the proposed project area. They must comply with the Endangered Species Act of 1973. This research depicts large amounts of quality Indiana bat habitat within Madison and Delaware Counties, therefore various development projects have the potential to destroy habitat for the species. Therefore mitigation procedures must be created so that the project does not impact a federally endangered species. Overall, the model created with this research can be used as a predictive tool. Sampling for an elusive bat species can be both time consuming and expensive. Having a predictive habitat model that can be used by a wildlife specialist with GIS knowledge is beneficial because it can take just a few hours and can give insight into how a species will be impacted by a possible developmental project. If any area that is projected by developed has the potential to boast an endangered species, a habitat model is a quick, inexpensive, efficient way of determining if sampling procedures will be required for the project to continue.

In terms of the Mounds Lake Reservoir Project, there is now evidence that the Indiana bat could be greatly impacted by the removal of large amount of habitat for the species. The habitat model can also be applied if proposed developmental projects do break ground. Mitigation measures are sometime applied to other parcels of land to mitigate the negative impact on a species where development is being conducted. This model has the ability to delineate tracts of forested land that have the ability to boast Indiana bat roosts that could be set aside for protection to mitigate the results of development within current Indiana bat habitat. The Mounds Lake

Reservoir Project may not be completed due to community and ecological concerns. This project still has the potential to be used as a predictive tool for development within the eastern Corn Belt region of the United States. If other developmental projects arise and there is a concern that the Indiana bat could potentially be negatively impacted, the habitat model can be applied to similar ecosystems within our region.

There were a multiple challenges with the creation of a habitat model for the Indiana bat. The first major challenge was the need for sampling data within Madison County. As stated before, the Indiana bat is an elusive and difficult species to sample. With the time constrains of this project, obtaining the proper permit to sample for a federally endangered species were not feasible. Therefore, historic data from a similar ecosystem (different counties) were used to create the habitat model. Having sample data from Madison and Delaware Counties would have been beneficial in the verification of the model because these data could have verified the model using current data in which all collection methods were known. Determining the statistical significance of the model created in ArcGIS was another challenge for the study because there are no specific tests to determine validity of an ArcGIS model. Using a Poisson Regression which analyzes count data was the analysis that best fit the data (matrix of environmental variables compared to presence locations) but there may be a more applicable statistical method for determining validity of the data that was not found during the scope of this research. As the habitat model was being revised during Trial 1 and Trial 2, it was evident that there was a need for ground data. Some of the GIS data used in the creation of the model was not specific enough to accurately depict the habitat requirements for the species.

There are multiple environmental variables within the research that would have been strengthened with ground data. Some of the GIS data did not represent the habitat requirements for the species due to the lack of specific data. In terms of distance from an impeding road, CFCC codes may not be able to translate into travel volumes. When verifying the model using Rush and Henry Counties, all of the presence locations were located within the predicted habitat except for a single presence location on an a priori basis. This presence location was within a close proximity to two separate and widely distributed habitat fragments as well as along a road that could be considered a travel corridor (but due to CFCC codes was considered an impeding road). In terms of future management, defining a roads ability to be used a travel corridor verses a road that impedes movement may need to be stratified. This study used CFCC codes to determine the travel volume of the roads within the study areas. For future habitat analysis and management of the species, the travel volume of each road may need to be classified by contacting the local travel department within each county and creating an amended attribute table with travel volume information for each road within the study area.

When defining the height of trees within a particular stand, the LandFire GIS data was not specific enough to discern a height threshold for Indiana bat roost use. The data was separated in to categories of 5-10, 10-25 and 25-50 meters in terms of tree height. Statistically there was no relevance to this data and the presence of Indiana bats. This does not agree with the previous research (Gardner, 1991) which could be due to the fact that trees of at least 5 meters in height have a probability of having exfoliating bark and cavities, depending on the tree species. Therefore, ground data defining tree heights per stand to a more accurate scale could be important in validating the environmental variable. If gathering ground data is not an option, using another technique in GIS could be beneficial. Another option that could yield the information pertaining to size of trees within a landscape could be age of the stand. Comparing historic GIS data of forested land to current GIS data of forested land could show stands of trees that have not had large scale cutting and therefore may have trees of larger dbh. This may not be the most accurate representation of size of trees in a woodlot because there are still instances when cutting could have been performed and a younger woodlot is now present. Understanding the importance of tree height on the overall selection of roosting habitat for the Indiana bat may require sampling within particular woodlots to determine if there are trees of adequate size to boast roosting.

For future research in Indiana bat habitat requirements and habitat modeling, using computer programs such as MaxEnt and MaxLike could be beneficial. These programs have their limitations but have validity in the scientific community. Creating a habitat model using one of these two programs could aid in managing this species as well as a decision-making tool for future developmental projects. If a habitat model is created using these programs it could be compared to the model created in this research to determine the overall reliability of using ArcGIS with training and test data. The importance of each environmental variable data that is given in these programs could also be compared to the Poisson Regression results to see if there are similarities in determine importance of these variable on Indiana bat presence.

6.1 Implications of Research

In addition to being a decision making tool for future developmental projects, this habitat model has the ability to be verified by data collected within Madison County. If the Mounds Lake Project continues, or another project of similar size, an environmental impact analysis to survey the presence/absence of the Indiana bat will be conducted to comply with the Endangered Species Act. Therefore, if an Indiana bat survey is conducted in Madison and Delaware counties, the model has the ability to be validated. The research could also be continued to further refine the model based on the current presence locations of Indiana bats within an area that has not been sampled in the last 40 years. Microhabitat measurements will be able to be sampled, such as specific tree heights, more accurate canopy closures as well as tree species of roosts. Even though this study may have the caveat of lacking microhabitat information, it still provides habitat characteristics important to the conservation of the study species.

Also, this model can be used as more than a decision making tool for possible developmental projects within this region but can be used as insight into the specific habitat requirements of an endangered species. This project sheds light on the importance of water resources to the Indiana bat. The historic presence locations used in the study were all significantly correlated with a close proximity to water. The need for water resources for drinking purposes as well as the open canopy for foraging has been retested in this study. Also, a larger range of canopy closures may beneficial when managing for the species. A completely closed or completely open canopy was shown to be unbeneficial to the Indiana bat which could be attributed to the fact that thermoregulation is difficult for the young as well as the adults during extremely warm and cold times of roosting season. The propensity for Indiana bats to roost in larger trees was described when understanding how tree height relates to dbh. Trees of at least 5 meters in height have the potential to boast Indiana bats. Anthropomorphic habitat was also shown to impact the roosting of the Indiana bat. Roads with high travel volumes may not have such a large impact on roosting Indiana bats as previous studies have shown. This could be due to the fact that roads with high travel volumes are not always in close proximity to large tracts of forested land. Highly populated areas were found to impact Indiana bat roosts due to noise and light pollution as well as fatalities due to higher volumes of people. There are tracts of forested land that could have potential to boast Indiana bats but are in too close of a proximity to highly populated areas to be utilized.

Overall, this study gives insight into the specific summer roosting habitat requirements for the Indiana bat within the eastern Corn Belt. Also, the habitat model created illustrates the possible impacts of large scale developmental projects within Madison and Delaware Counties on the endangered Indiana bat. There is critical habitat for the Indiana bat within the proposed location of the Mounds Lake Reservoir Project. Alternative projects have also been proposed within these counties for economic development in lieu of the Mounds Lake Reservoir Project. These projects could use this habitat model as a tool to determine their overall impact on the species. All of this information has the potential to aid in decision making procedures and management of this endangered species in the future as well as aid in the decision making process of developmental projects within the eastern Corn Belt.

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Appendix

Table 13: Poisson regression results for the 5 statistical models performed on the environmental variables compared to the presence locations for the Indiana bat within Randolph County

Model 1			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig
Intercept	0.146	0.5892	-1.009	1.301	0.061	1	0.804
CC (%)	0.021	0.008	0.005	0.037	6.91	1	0.009
Distance from Water	0.005	0.0016	0.002	0.009	11.765	1	0.001
Distance From Development	8.036E-05	2.922E-05	2.309E-05	0.000	7.563	1	0.006

Model 2			95% Walk Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig
Intercept	-151.68	50.691	-251.033	-52.328	8.954	1	0.003
X	2.138 E-5	2.3717 E -5	-2.511E-05	6.79E-05	0.813	1	0.367
Y	3.086 E-5	9.4595 E -6	1.232E-05	4.94E-05	10.642	1	0.001
CC (%)	0.010	0.010	-0.009	0.029	1.050	1	0.306
Forest Height	0.005	0.007	-0.008	0.018	0.582	1	0.445
Distance from Water	0.001	0.002	-0.003	0.006	0.385	1	0.535
Distance from Development	0.000	9.94E-05	4.57E-05	0.000	5.856	1	0.016
Distance from Impeding Road	1.00E-03	6.00E-04	0.00	0.002	2.435	1	0.119

Model 3			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig
Intercept	-122.872	38.2467	-197.834	-47.91	10.321	1	0.001
Y	2.76E-05	8.61E-06	1.08E-05	4.45E-05	10.294	1	0.001
CC (%)	0.013	0.0092	-0.005	0.031	1.958	1	0.162
Forest Height	0.005	0.007	-0.008	0.018	0.532	1	0.466
Distance from Water	0.002	0.002	-0.002	0.006	1.295	1	0.255
Distance from Development	0.00E+00	4.13E-05	7.89E-05	0.000	14.996	1	0.000
Distance from Impeding Road	0.001	0.000	0.000	0.001	1.704	1	0.192

Table 13 (continued): Poisson Regression results for 5 models that were performed on the environmental variables compared to the presence locations for the Indiana bat within Randolph County

Model 4			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig
Intercept	-103.584	34.8887	-171.964	-35.203	8.815	1	0.003
Y	2.32E-05	7.84E-06	7.88E-06	3.86E-05	8.795	1	0.003
CC (%)	0.019	0.0081	0.003	0.035	5.481	1	0.019
Forest Height	0.005	0.0068	-0.008	0.019	0.612	1	0.434
Distance from Water	0.004	0.0016	0.001	0.007	6.027	1	0.014
Distance From Development	0.000	3.57E-05	6.31E-05	0.000	13.901	1	0.000

Model 5			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig
Intercept	-102.539	34.7166	-170.583	-34.496	8.724	1	0.003
Y	0.000	7.80E-06	7.79E-06	3.84E-05	8.752	1	0.003
CC (%)	0.017	0.0077	0.002	0.032	4.858	1	0.028
Distance from Water	0.004	0.0016	0.001	0.007	6.279	1	0.012
Distance From Development	0.000	3.23E-05	5.82E-05	0	14.152	1	0.000